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Analysis of catch options for aboriginal and recreational fisheries for Atlantic salmon from the Margaree River (Nova Scotia) for 2012

Analyse des options de captures dans les pêches autochtones et récréatives du saumon atlantique de la rivière Margaree (Nouvelle-Écosse) pour 2012

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ABSTRACT

A risk analysis of catch options for aboriginal and recreational fisheries for Atlantic salmon (*Salmo salar*) from the Margaree River (Nova Scotia) for 2012 is presented. This analysis is provided in response to a request from the First Nations communities of Nova Scotia for additional food, social and ceremonial access to salmon. The forecasts of returns of small salmon (<63 cm fork length) and large salmon (>= 63 cm fork length) in 2012 are based on a hierarchical model that incorporates the uncertainties and the variations in annual returns for the years 1987 to 2011. A correction for autocorrelation of the time series is incorporated in the forecasts. Recreational fisheries effort is predicted from the previous four years and catches and catch rates for 2012 are estimated using catchability coefficients by salmon size group from the recreational fishery derived during the 1988 to 1996 assessment years. The management objectives are to meet or exceed with a high probability the previously defined conservation requirement for large salmon (1,036 fish) and a corresponding small salmon requirement of 582 fish for a 1:1 female to male ratio. An alternate objective for small salmon is defined based on an equivalent exploitation rate in the fisheries for small salmon and large salmon. The expected surplus to conservation of large salmon in 2012 that would result in a 95% probability of meeting or exceeding conservation is 917 fish. For small salmon, there is a 92% chance that the returns would exceed the 582 fish objective. The expected surplus of large salmon represents a median exploitation rate of 27.5%. For this exploitation rate and at a 50% chance of meeting or exceeding it, there would be a catch option of 271 small salmon in 2012.

RÉSUMÉ

Une analyse des risques de différentes options de captures dans les pêches autochtones et récréatives au saumon atlantique (*Salmo salar*) de la rivière Margaree (Nouvelle Écosse) pour l'année 2012 est présentée. Cette analyse a été préparée en réponse à une demande par les Premières Nations de la Nouvelle-Écosse pour des augmentations aux allocations de saumon dans les pèches pour des fins alimentaires, sociales et rituelles. Un modèle hiérarchique qui incorpore les incertitudes et les variations inter-annuelles des montaisons annuelles pour les années 1987 à 2011 est utilisé pour fournir les prévisions des montaisons prévues pour 2012 de petit saumon (longueur à la fourche < 63 cm) et de grand saumon (longueur à la fourche >= 63 cm). Les prévisions sont ajustées pour tenir en compte des autocorrélations présentes dans les séries temporelles. L'effort de la pêche récréative pour 2012 est prédit par la moyenne des efforts des quatre années antérieures. Les captures et les taux de captures dans cette pêche en 2012 sont estimés en utilisant les coefficients de capturabilités pour les petits et les grands saumons. Ces derniers ont été évalués pour les années d'évaluation de 1988 à 1996. Les objectifs de gestion sont de rencontrer ou dépasser avec une probabilité élevée les besoins de conservation de grand saumon (1 036 poissons) et l'objectif correspondant de 582 petits saumons qui donnerait un rapport de un mâle pour une femelle. Un objectif alternatif pour les petits saumons est proposé. Celui-ci correspond à un taux d'exploitation équivalent pour les petits saumons et les grands saumons. L'excédentaire à la conservation pour les grands saumons en 2012 qui correspond à une probabilité de 95% de rencontrer ou dépasser les besoins de conservation est 917 grands saumons. Pour les petits saumons, il y a 92% chance que la montaison en 2012 soit supérieure à l'objectif de 582 poissons. L'excédentaire de grands saumons correspond à un taux d'exploitation à une valeur médiane de 27,5%. Pour 50% chance d'être égal ou supérieur à ce niveau d'exploitation, les captures potentielles de petits saumons en 2012 s'élèvent à 271 poissons.

1. INTRODUCTION

The Margaree River (western Cape Breton Island, Nova Scotia) has the largest Atlantic salmon (Salmo salar) population in Nova Scotia. The Atlantic salmon returns to the Margaree River are predominantly large salmon (fork length ≥ 63 cm; also known as multi-sea-winter), the majority of which are female (LeBlanc et al. 2005; Breau et al. 2009). Small salmon (fish with fork length < 63 cm), generally referred to as grilse, are less abundant than the large salmon and are comprised of a high proportion of males (LeBlanc et al. 2005; Breau et al. 2009). In contrast to most other rivers of DFO Gulf Region Nova Scotia where salmon typically return to rivers after August, salmon return to the Margaree River from early June to November and the fall run (after August) is usually more abundant than the early run. There is an Atlantic salmon hatchery stocking program on the Margaree River which uses broodstock collected from the river annually to produce juveniles for stocking as fall fingerlings and as 1-year old smolts (Breau et al. 2009). Based on angler logbooks for the years 2004 to 2011, the contribution of hatchery-origin salmon to the catches of salmon in the Margaree River had a median value of 3% (range: 0 to 16%) for small salmon and a median value of 2% (range: 0 to 35%) for large salmon (C. Breau, DFO Unpublished data).

Atlantic salmon in the Margaree River are exploited in aboriginal peoples' food, social and ceremonial (FSC) fisheries and in recreational fisheries. Fisheries management measures vary by user group. FSC allocations of Atlantic salmon from the Margaree River to First Nations in Nova Scotia in 2011 totaled 345 large salmon and 135 small salmon. In addition, the Native Council of Nova Scotia (off-reserve aboriginal peoples) had an FSC allocation of 1,820 fish (small salmon and large salmon combined) that could be taken from a large number of rivers in Nova Scotia including the Margaree River. The fishing season for the Native Council of Nova Scotia is from January 1 to May 14th for small salmon and large salmon males only, May 15th to 31st for male and female small salmon, and June 1st to November 5th for small salmon only (DFO 2008).

Recreational fisheries for Atlantic salmon in Nova Scotia are managed on the basis of daily, seasonal and size retention limits, seasonal openings, and gear restrictions. An angling licence issued by the province of Nova Scotia is required to fish recreationally for Atlantic salmon. Only artificial flies are permitted and only small salmon can be retained, all large salmon must be released back to river after capture. The daily and season retention limits for small salmon apply to individual licences and are 2 and 4 small salmon, respectively. The season retention limit for small salmon was reduced from eight fish to four fish in 2008. All retained small salmon must be marked with single use carcass tags which are issued with each provincial fishing licence. The maximum daily catch and release limit is four fish, regardless of size. The angling season in the Margaree River is open from June 1 to October 31, in most years. A catch report stub is attached to each angling licence and anglers are required to return the catch report of catches and effort by river to the province of Nova Scotia even if no effort was expended during the year.

First Nations communities of Nova Scotia requested an increase in the allocations of small salmon and large salmon from the Margaree River for 2012 based on their aboriginal right to first access to fish for FSC purposes, after conservation requirements are met. DFO Fisheries and Aquaculture Management requested advice on the risks to meeting or exceeding the conservation requirements for Atlantic salmon in the Margaree River for various fishery management and catch options. In addition, an estimate of the available surplus of salmon that would result in a low probability (<5%) of failing to meet or exceed the conservation requirements in 2012 was requested.

No forecast of expected returns of salmon and no forecast or analysis of catch options for the Atlantic salmon fisheries for 2012 were provided in the recent assessment (DFO 2012). The following document provides a risk analysis of catch options for the Atlantic salmon fisheries in the Margaree River in 2012. The document summarizes the conservation requirements for the river, the model which is used to assess the abundance of salmon in the Margaree River and to provide a forecast for 2012, the catch options scenarios and the fishery characteristics, and provides the estimated probability of meeting or exceeding the conservation requirements for each fishery scenario. Uncertainties are highlighted and recommendations for future activities to improve the assessment are provided.

2. CONSERVATION REQUIREMENT FOR THE MARGAREE RIVER

Conservation requirements for Atlantic salmon in all rivers of the Gulf Region were defined as an egg deposition rate of 2.4 eggs per m^2 of wetted habitat area for juvenile production (CAFSAC 1991a). The conservation requirement was defined as equivalent to a limit reference point. DFO and international management policies are to manage the resource such that there is a very low probability (5% or less) of falling below this limit reference point (DFO 2009; ICES 2012).

Because the majority of the salmon run to the Margaree are comprised of large salmon and these are mostly female, the objective is to obtain all the eggs for the conservation requirement from large salmon (CAFSAC 1991b). CAFSAC (1991b) also provided a value for small salmon based on the objective of ensuring a 1:1 male to female ratio at spawning time, corresponding to the conservation requirement for large salmon. This objective has in the past been used in some rivers but not the Margaree River to manage access for fisheries on small salmon in cases where the large salmon returns were below conservation requirement. A firm biological basis for this objective has yet to be documented.

The conservation requirement of large salmon for the Margaree River is calculated as follows. The egg deposition rate is multiplied by the estimated fluvial habitat area in the Margaree River used for juvenile production. The total habitat area has been estimated to be 2.798 million m^2 (Marshall 1982) and the total egg requirement is therefore 6.714 million eggs. At an assumed fecundity of 6,483 eggs per large salmon (Chaput et al. 1992), the conservation egg requirement is obtained from 1,036 large salmon. Based on average historical biological characteristics of large salmon in Margaree River (Marshall 1982), the required 1,036 large salmon are comprised of 777 females (0.75 * 1,036) and 259 males (0.25 * 1,036). The biological characteristics were summarized from large salmon sampled at a trap and creel surveys in the Margaree River between 1973 and 1977 (Marshall 1982). More contemporary sampling indicates that the inter-annual variation in the proportion of females in large salmon ranges from 0.62 to 0.79 (LeBlanc et al. 2005). The deficit males (518 fish) in the large salmon component required to meet the 1:1 male to female objective come from the small salmon. At a male proportion of 0.89 in the small salmon (Marshall 1982), the 518 deficit males are equivalent to 582 small salmon.

An alternative objective to the 1:1 male to female ratio is proposed for small salmon for the Margaree River. The alternate objective is to manage for a similar exploitation rate (fisheries losses relative to returns) for small salmon and large salmon. Managing fisheries such that the exploitation rate applies equally to all age and size groups of salmon is consistent with principles of preventing size-selective or age-selective fishing pressures on aquatic resources. This objective is proposed for the following reasons. Large salmon are more abundant than small salmon and the small salmon objective defined by CAFSAC (1991b) has been difficult to

attain in the past. More importantly, it is preferable to maintain the age/size structure of the salmon population. The exploitation rate objective is determined as the ratio of fisheries losses of large salmon to returns of large salmon that results in a 5% or lower chance of not meeting the conservation requirement for large salmon. The small salmon harvest would be assessed relative to a 50% chance (risk neutral) of being above this target exploitation rate. A risk neutral objective was used for small salmon because the small salmon objective is a secondary objective to maintain the size structure of the salmon population in Margaree River rather than a conservation requirement.

3. MATERIALS AND METHODS

In order to conduct the risk analysis of catch options relative to the objective of meeting or exceeding the conservation requirement in 2012, the following information is needed: a model to predict abundance of large salmon and small salmon in 2012, a forecast of the catches and losses from the recreational fishery in 2012 for different management scenarios, and catch option scenarios for the FSC aboriginal fisheries.

3.1 MODEL TO PREDICT ABUNDANCE OF LARGE SALMON AND SMALL SALMON IN 2012

A mark and recapture experiment was conducted in Margaree River between 1988 and 1996 to estimate the returns of small salmon and large salmon. Fish were captured in estuary trapnets, marked with individually numbered external tags and released to the river to continue their migration. Fish were recaptured 1) by anglers participating in a logbook program during the recreational fishing season, 2) in dedicated seining programs for a few years, and 3) at a counting fence on Lake O'Law Brook, a tributary of the Margaree River. The marking, recapture and catch data from these activities are summarized in Appendix 1 - Table 1. Details of the annual programs are available in various assessment reports (Claytor and Chaput 1988; Claytor and Jones 1990; Chaput and Jones 1991, 1992; Chaput et al. 1992, 1993, 1994; Claytor et al. 1995; Marshall et al. 1996, 1997).

During the same time period as the mark and recapture experiments, angling catch and effort data were recorded in logbooks by a select group of volunteer anglers. Catch and effort data was also available from a larger pool of Atlantic salmon anglers that returned a catch report card (provincial license stub) at the end of the fishing season. The angling effort and catches of small salmon and large salmon for the various methods are summarized in Appendix 1-Table 2.

The angling catch and effort data were used in conjunction with the mark and recapture data and return estimates for the years 1988 to 1996 to estimate the catchability coefficients (q, per rod-day of effort) for the anglers returning logbooks and the larger pool of anglers returning licence stubs. Annually, between 39 and 70 anglers returned logbooks detailing their angling activities in the Margaree River. Annually, between 640 and 6,643 anglers returned their licence stubs detailing their angling activity in Nova Scotia from which Margaree River-specific catches and effort were extracted.

For 1987 and during 1997 to 2011, the returns of Atlantic salmon to the Margaree River are estimated using the catchability coefficients estimated for logbook anglers and licence stub anglers, developed during the mark and recapture period, combined with the angling catch and effort data in logbook reports and returned license stubs.

The model is described in detail in Appendix 1 and a version (although not described) was used by Breau et al. (2009) to assess returns and status of Atlantic salmon in the Margaree River. Model coding in OpenBugs is provided in Appendix 2.

A forecast of returns for 2012 is required to do the risk analysis. The previously used assessment model was modified by incorporating a hierarchical structure for the annual estimates of returns of small salmon and large salmon. The best estimate of returns in a given year without auxiliary information (catch and effort data) is described by the parameters of the common distribution. This is similar to the idea that the returns in 2012 are expected to be the average returns observed over a selected time period in the past. The hierarchical structure incorporates the variance in the annual returns as well as the uncertainty associated with the individual annual estimates. This modification is described in Appendix 1.

The forecasted returns of small salmon and large salmon in 2012 are based on the hierarchical model structure for the years 1987 to 2011.

For the model used to predict returns for 2012, the estimated returns (N) in year *y* for size group *g*, are drawn from a lognormal distribution with hyper-parameters μ_g (mean) and ε_g (error):

$$N_{g,y} \sim \log normal(\mu_g, \varepsilon_g) \qquad (1)$$

with $\varepsilon_g \overset{iid}{\sim} Normal(0, \sigma_g^2)$

We examined the assumption that the residuals of the estimated annual returns and the predicted return based on the hyper-parameters are independent and identically distributed (not autocorrelated) by calculating their first order autocorrelation. The residuals are calculated as:

$$\hat{w}_{g,y} = \log(N_{g,y}) - \mu_g \qquad (2)$$

The first order autocorrelation is calculated by size group as (Hilborn and Walters 1992, p. 281):

$$\phi_g = \left[\frac{Y-1}{Y-1-k}\right] \frac{\sum_{y=1}^{Y-k} \hat{w}_{g,y}\hat{w}_{g,y+k}}{\sum_{y=1}^{Y} \hat{w}_{g,y}^2} \qquad (3)$$

with k = 1 (lag in years) and Y = 25 (1987 to 2011).

A first-order autoregressive model is used to predict the returns of small salmon and large salmon in 2012:

$$\begin{aligned} \log(N_{g,2012}) &= \mu_g + \hat{w}_{g,2012} \\ \hat{w}_{g,2012} &= \hat{w}_{g,2011} * \phi_g + \varepsilon_{g,2012} \\ \varepsilon_{g,2012} &= Normal(0, \sigma^2_{g,2012}) \\ \sigma^2_{g,2012} &= \left(1 - \phi_g^2\right) * \sigma_g^2 \end{aligned} \qquad (4)$$

where ϕ_g is the autocorrelation parameter bounded by $|\phi_g| <= 1$, and σ_g^2 as in equation (1) above.

3.1.1 Treatment of the small salmon return in 1996

Following on preliminary analyses at the science peer review meeting, concerns were raised about the exceptional nature of the estimated return of small salmon in 1996 and after explanations, it was concluded that the 1996 return of small salmon may be dissimilar to the other years because of an exceptional release of hatchery-origin smolts to the Margaree River in 1995 (Marshall et al. 1996). As a result, the prediction model was run excluding 1996 from the estimation of the hyper-parameters of the common distribution (used in the forecast for 2012) and verification of the autocorrelation of the small salmon return series was done by excluding the 1996 estimation. By excluding the estimates of returns for 1996, the number of years to estimate the hyper-parameters is reduced to 24 (1987 to 1995, 1997 to 2011) and the number of adjoining residual pairs for autocorrelation analysis is 22, rather than 24 with the full data set.

3.2 PREDICTION OF CATCHES AND LOSSES FROM THE RECREATIONAL FISHERY IN 2012

In this document, catch rate refers to an estimate of the proportion of the returns of salmon handled in the fishery, and includes both kept and released fish. Exploitation rate refers to the proportion of the estimated returns of salmon which are lost due to the fishing activity and includes fish retained and mortality associated with catch and release.

For the risk analysis for 2012, catches from the recreational fishery are predicted using the predicted recreational fishery effort, the estimated catchability coefficient by size group, and the predicted returns by size group (from equation 4 above).

Catch and effort for the recreational fishery are estimated from provincial licence stub returns. Anglers are required to return information on effort, small salmon retained, small salmon released, and large salmon released by river and date using a licence stub which is attached to the provincial angling licence. Although reporting is mandatory, only a fraction of anglers return the licence stubs voluntarily. In some years, reminder letters were sent in the early winter to prompt non-reporting anglers to submit their stubs but even in these cases, less than 95% of the licence stubs were returned. In recent years, the proportion of voluntary returns has been less than 30% (Table 1). Total catch and effort are adjusted based on the proportion of reports returned, after adjustment for differences in angling success and effort between volunteer anglers and anglers reporting after one or more reminder prompts.

3.2.1 Predicting effort

Estimated recreational fishery effort in the Margaree River shows a steep decline in activity during 1987 to 2011; a high effort period during 1987 to 1995 ranging from 12,000 to 15,000, a mid-level effort over three years 1996 to 1998 ranging from 9,000 to 10,000 rod days, and a lower level of effort since 1999 to 2011, ranging from 7,500 to 9,000 rod days (Table 1; Fig. 1). There was a reduction in the season retention limit for small salmon from 8 to 4 in 2008. The consequence of this regulatory change on angling effort is not known but angling effort in the recent four years has been at the same level as the estimated effort over the period 1999 to 2007. However, we chose to predict effort for 2012 based on the estimates corresponding to 2008 to 2011, corresponding to a common management period. We model the effort using a t-distribution with 4 degrees of freedom:

$$Eff_y \sim tdist(\mu.Eff, \varepsilon.Eff, 4) \quad (5)$$

Vague priors are given for $\mu.Eff$ (lognormal with mean 0 and standard deviation 10) and $\varepsilon.Eff$ (inverse gamma (0.01, 0.01)). The predicted effort for 2012 (Eff_{2012}) is derived from the same t-distribution with estimated parameters. The choice of 4 dfs is arbitrary, has been used in other studies, and generates heavier tails than a normal distribution although the CV of the predicted value for effort for 2012 is only 7% (mean = 7,821, std.dev = 527). Use of 3 dfs resulted in slightly heavier tails but the CV was only 10%.

3.2.3 Predicting catches

Catch rates by size group (g) in the recreational fishery in 2012 are calculated as:

$$CR_{g,2012} = 1 - \exp(-Eff_{2012} * q_g) \quad (6)$$

and catch of salmon by size group is modelled as:

$$C_{g,2012} \sim bin(CR_{g,2012}, N_{g,2012}) \quad (7)$$

with $N_{g,2012}$ the predicted return of salmon by size group g in 2012.

Some of the small salmon catch was expected to be released. The proportion of the catch of small salmon released is modelled using a beta distribution.

$$p\mathrm{Rel}_{g,y} \sim beta(C.\mathrm{Rel}_{g,y}, C.\mathrm{Ret}_{g,y}) \quad y = 2008\ to\ 2011;\ Y = 4 \quad (8)$$

The predicted proportion of the small salmon catch released for 2012 is calculated as the mean of the annual proportions from equation 8.

$$p\mathrm{Rel}_{g,2012} = \sum_{y}^{Y} p\mathrm{Rel}_{g,y} / Y; \quad y = 2008\ to\ 2011;\ Y = 4 \quad (9)$$

The years 2008 to 2011 correspond to the period with a season retention limit of four small salmon. These years were selected because the proportion of small salmon released has been increasing over time and the proportions for the years 2008 to 2011 are among the highest of the time series (Fig. 2; Table 1).

The predicted number of small salmon released in 2012 is modelled as:

$$C.\mathrm{Rel}_{g,2012} \sim bin(p\mathrm{Rel}_{g,2012}, C_{g,2012}) \quad (10)$$

For large salmon, which must all be released in the recreational fishery, $C.Rel_{g,2012}$ equals $C_{g,2012}$.

For the scenario with a catch and release angling fishery in October only, the proportion of the catch of salmon by size group captured in October is modelled using a beta distribution.

$$pC.Oct_{g,y} \sim beta(C.Oct_{g,y}, C.Other_{g,y}) \quad y = 1997\ to\ 2011;\ Y = 15 \quad (11)$$

The proportion of the total season catch taken in October for 2012 is calculated as the mean of the annual proportions from equation 11.

$$pC.Oct_{g,2012} = \sum_{y}^{Y} pC.Oct_{g,y} / Y; \qquad y = 1997 \; to \; 2011; \; Y = 15 \tag{12}$$

The predicted catch of salmon for October 2012 is modelled using the mean proportion (equation 12) applied to the predicted total catch by size group for 2012.

$$C.Oct_{g,2012} \sim bin\left(pC.Oct_{g,2012}, C_{g,2012}\right) \tag{13}$$

This assumes that angling effort will not be displaced to October as a result of the restricted opening of the recreational fishing season.

3.2.4 Predicting losses

For small salmon, the catch retained is the difference between the predicted catch and the predicted released (equation 7 minus equation 10).

The predicted numbers of salmon by size group which die as a result of catch and release are estimated assuming a 5% probability of mortality:

$$CRmort_{g,2012} \sim bin\left(0.05, C.rel_{g,2012}\right) \tag{14}$$

Typically, 3% mortality is attributed to catch and release in some other rivers of Gulf Region (DFO 2012). Historically, bacterial kidney disease has been present in the Margaree River salmon population and this was assumed to result in increased mortality of salmon from catch and release fishing. For this reason, a 5% mortality rate was applied to the catch and release fish angled in the Margaree River independent of fish size and capture season (CAFSAC 1991b; Breau et al. 2009). The 5% value is not based on observations from the Margaree River.

Losses of salmon from the angling fishery ($LossSport_g$) in year y are estimated as the sum of retained fish and estimated mortality from caught and released fish.

$LossSport_{g,2012} = CRet_{g,2012} + CRmort_{g,2012}$

Since no large salmon can be retained, the loss of large salmon in the angling fishery is simply the predicted losses due to catch and release mortality.

3.5 FISHERY SCENARIOS FOR 2012 AND RISK ANALYSIS

The request from fisheries management was to evaluate increased aboriginal peoples FSC allocations from the 2011 allocation level of 345 large salmon and 135 small salmon combined with three recreational fishery management scenarios:

3.5.1 Large salmon

Risks relative to conservation requirements are evaluated for FSC allocations ranging from 345 fish to a maximum of 1,645 large salmon by 50 fish increments and

a. Recreational fishery management in 2012 as in 2011 (season and daily retention limits for small salmon of 4 and 2, respectively, mandatory catch and release of large salmon, maximum daily catch and release limit of four fish regardless of size, fly fishing only with artificial flies, season from June 1 to October 31),

b. Recreational fishery open only in October and with mandatory catch and release for all sizes of salmon, and

c. Recreational fishery closed.

3.5.2 Small salmon

For small salmon, the risk analysis is presented as the probability of exceeding the median exploitation rate as derived from the large salmon conservation requirement, and also of exceeding an objective of 582 small salmon to meet the 1:1 male to female ratio for spawners. The following fishery scenarios are analyzed for small salmon (Table 4): risks relative to the objective of 582 small salmon and the objective of similar exploitation rate to large salmon are evaluated for small salmon FSC allocations ranging from 135 fish to a maximum of 635 small salmon by 50 fish increments, and recreational fishery scenarios as described for large salmon.

For each scenario, the spawners are calculated as the difference between forecast returns and expected losses.

The probability of meeting the conservation requirement for large salmon for each fishery scenario is calculated from the posterior distribution of spawners relative to the conservation requirement of 1,036 large salmon.

The potential forecast surplus to the conservation requirement of large salmon in 2012 is defined as the catch that provides a low probability (5% or less) of failing to meet the conservation requirement for large salmon in 2012. It is calculated directly from the posterior distribution of the predicted returns and is simply the difference between the 5th percentile of the forecast returns for 2012 and the conservation requirement of 1,036 large salmon.

$$Surplus_{large,2012} = Return.large_{5thperc,\ 2012} - 1{,}036$$

The exploitation rate objective for small salmon (ER_{2012}) is taken as the ratio of the predicted surplus of large salmon to the median predicted return of large salmon in 2012.

$$ER_{2012} = Surplus_{large,2012} \,/\, Return.large_{median,2012}$$

The probabilities of achieving the small salmon objective are calculated from the posterior distribution of the calculated exploitation rate on small salmon in 2012 for each fishery scenario.

4. RESULTS

The sale of recreational Atlantic salmon fishing licences is managed by the province of Nova Scotia. Licence sales from 1987 to 1990 varied between 7,191 and 8,615 licenses annually (Table 1). Since 1998, annual license sales have ranged from 1,938 to 2,600 licenses (Table 1). The reporting rate for license stubs has declined over time and in 2011, only 24% of license holders returned their license stubs without a prompt; the return rate increased to 33% with a reminder letter (Table 1).

Estimated angling effort is positively associated with annual license sales (Fig. 1A). Estimated angling effort in Margaree River from license stubs declined from an average of about 14,000 rod days during 1987 to 1994 to about 8,000 rod days during 1999 to 2011 (Fig. 1B; Table 1).

Estimated catches of large salmon exceeded 2,100 fish in 1997, reached a low of just over 600 fish in 2002 but rose again to about 1,300 fish during 2003 to 2005 (Fig. 2A; Table 1). The largest estimated catch occurred in 2011 at 2,159 large salmon caught and released. Small salmon catches (kept and released) are less than those of large salmon, the highest value recorded was in 1996 at over 1,200 fish and the lowest since 1997 was reported in 2009 at 171 fish (Fig. 2B; Table 1). The observed values of effort and catches (returned licence stubs) represented a high proportion of the estimated values (> 75%) over most of the time series but declined to between 36% and 68% in the last nine years, except for 76% in 2005 (Fig. 2C).

Over the time series 1987 to 2011, there has been a gradual increase in the number and proportion of small salmon released (Fig. 3; Table 1). The average percentage of small salmon released by recreational anglers was estimated to be 37% from 1987 to 2003. In 2004 to 2007, the last four years with a season bag limit of eight small salmon, 48% of small salmon caught were estimated to have been released. Since the management measures changed to a season bag limit of four small salmon (2008 to 2011), the proportion of small salmon released by anglers has increased to an average of 61% (Fig. 3; Table 1).

The catch in October and the proportion this catch represents of the total annual catch has been decreasing since 2001 and was lowest in 2011 for both size groups (Fig. 4; Table 1). Proportionally more of the total season large salmon catch is reported in October than is the case for small salmon (Fig. 4; Table 1)

4.1 ESTIMATES OF RETURNS OF LARGE SALMON AND SMALL SALMON

Posterior distributions of large salmon return estimates show a wide annual variation, over the period 1987 to 2011 (Fig. 5; Table 2). The highest returns, at a median value of about 5,700 large salmon, occurred in 2011 whereas the lowest returns of less than 2,000 large salmon were estimated for 1993 and 2002.

Posterior distributions for small salmon returns also show wide annual variation (Fig. 6; Table 3). The highest return, at a median value of about 2,700 small salmon, occurred in 1996 and was exceptional relative to all the other years. The very high return in 1996 was in large part attributed to a high abundance of hatchery-origin small salmon in the river that year, although returns of wild fish were also very high as shown by the high return of large salmon in 1996. Two temporal trends were observed in the estimated returns of small salmon. The estimated returns decreased from 1987 to 1995 and the estimates gradually increased from 1997 to 2011. Since 1997, returns (median value) of small salmon have varied between 390 and 1,437 fish annually (Table 3; Fig. 6).

4.2 CATCH RATES AND LOSSES IN THE RECREATIONAL FISHERY

Estimated catchability coefficients are higher for small salmon than for large salmon, for both logbook anglers and from licence stub reports but are comparable within size groups for the two reporting systems (Fig. 7). The annual catch rates for large salmon declined over the period 1987 to 2004, and leveled off from 2005 to 2011 (Fig. 8A, Table 2), a reflection of the changes in reported and estimated effort (Figs. 1 and 2, Table 1). Median catch rates for large salmon during 1987 to 1995 varied between 0.52 and 0.61 and declined to 0.33 in 2000, corresponding to the second lowest reported effort for the river (Fig. 8A, Tables 1 and 2). Small salmon catch

rates (median value) varied from just under 0.56 to 0.65 during 1987 to 1995 and were lowest in 2000, 2002 and 2003 at 0.37 (Fig. 8B, Table 2), corresponding to low effort years (Figs. 1 and 2; Tables 1 and 3).

4.3 SPAWNERS AND ATTAINMENT OF CONSERVATION

Returns (5th percentile) of large salmon, before any fisheries removals, exceeded the conservation requirements every year during 1987 to 2011 (Fig. 5; Table 2). Returns (5th percentile) of small salmon, before any in-river fisheries removals, were below the 582 small salmon objective in four years between 1987 and 2011 but the median estimated return exceeded the objective in all years except for 2009 (Fig. 6; Table 3).

The estimated loss of large salmon as a result of catch and release mortality has been less than 110 large salmon annually for 1987 to 2011, corresponding to annual exploitation rates of less than 0.031 (Table 2). The estimated total losses of small salmon in the recreational fishery, including catch and release mortality and small salmon retained has varied between 201 and 829 small salmon in 1987 to 1997 (Table 3) corresponding to exploitation rates greater than 0.32 (except 0.12 in 1996). Since 1998, the exploitation rate on small salmon has been at or below 0.30 (Table 3).

After accounting for fisheries losses of large salmon from the recreational fisheries and assuming that the FSC allocation of 345 large salmon had been taken annually, conservation requirements for large salmon were exceeded every year, even at the 5th percentile of the spawner estimates (Fig. 9B). After accounting for the removals of small salmon in the recreational fishery only, the estimated number of small salmon spawners (median value) exceeded the secondary objective of 582 small salmon spawners in 16 of 25 years between 1987 and 2011 but the 5th percentile of the estimated small salmon spawners was below the objective in 17 of 25 years (Fig. 10A). After accounting for removals in the recreational fishery and assuming that the FSC allocation of small salmon (135 fish) had been taken every year, the median value of the estimated small salmon spawners was below the secondary objective in 16 of 25 years and the 5th percentile of the estimated spawners after all fisheries removals was below the secondary objective in 21 of 25 years (Fig. 10B).

4.4 PREDICTED RETURNS, CATCHES AND LOSSES FROM RECREATIONAL FISHING, AND SURPLUSES FOR 2012

There is a significant positive autocorrelation in the predicted residuals of large salmon returns (0.19 median, 5th and 95th percentiles: 0.13 to 0.32) (Fig. 11A, Table 4). The predicted return of large salmon in 2012, uncorrected for autocorrelation is 2,921 fish (median value) with a 95% probability that the return would be greater than 1,692 fish (Fig. 5, Table 4). The predicted value corrected for autocorrelation is 3,338 fish (median value) with a 95% probability that the return would be at least 1,953 fish (Fig. 5; Table 4).

For the small salmon time series, covering the period 1987 to 2011, there is a significant negative autocorrelation in the residuals (-0.18 median, 5th and 95th percentiles: -0.25 to -0.03) (Table 4). For the 1987 to 2011 time series but excluding 1996, there is a weak positive autocorrelation in the residuals (0.096 median, 5th and 95th percentiles: 0.007 to 0.229) (Fig. 11B; Table 4). The forecast return of small salmon in 2012, uncorrected for autocorrelation, is 940 fish with a high probability (95%) that there would be at least 493 fish (Fig. 6; Table 4). The forecast return corrected for autocorrelation is 985 fish with a 95% probability the return would be greater than 523 fish (Fig. 6; Table 4).

The estimated catchability coefficient from the recreational fishery (based on licence stub data) for large salmon is $5.58 * 10^{-5}$ (5^{th} to 95^{th} percentile range $4.65 * 10^{-5}$ to $6.74 * 10^{-5}$). For small salmon, the estimated catchability coefficient is higher at $6.10 * 10^{-5}$ (5^{th} to 95^{th} percentile range $4.71 * 10^{-5}$ to $7.93 * 10^{-5}$). At a predicted effort in the recreational fishery in 2012 of 7,851 rod days (5^{th} to 95^{th} percentile range 5,689 to 10,020), the proportions of the returns expected to be angled (catch rates) are 0.35 for large salmon and 0.38 for small salmon (Table 4).

In accordance with the precautionary approach of having a low probability (<5%) of the egg depositions being less than conservation requirement, the predicted surplus of large salmon for 2012 is 917 large salmon (5^{th} percentile of the predicted returns of 1,953 fish, and a conservation requirement of 1,036 large salmon). The exploitation rate in 2012 if the 917 large salmon were harvested had a median value of 27.5%.

For small salmon, there is a 92% probability that the returns of small salmon would exceed the objective of 582 small salmon in 2012. At a target exploitation rate of 27.5%, the available small salmon harvest in 2012 is 271 small salmon (5^{th} to 95^{th} percentile range 144 to 521 fish).

4.5 RISK ANALYSES OF FISHERIES SCENARIOS

4.5.1 Fishery scenario 1

Expected losses of large salmon from catch and release mortality are 59 fish (5^{th} and 95^{th} percentiles: 29 to 104) (Tables 4, 5). The exploitation rate on large salmon would be 13% with current fisheries (recreational plus FSC allocation of 345 large salmon). The expected exploitation rate (fish lost to fisheries) on large salmon varies from 13% to 54% of the expected return for FSC allocations ranging from 345 to 1,645 fish and a recreational fishery in 2012 as in 2011.

At a 5% risk level of failing to meet the conservation requirement, the total projected surplus to conservation requirement for 2012 is 917 large salmon. With a recreational fishery in 2012 as in 2011, the FSC allocation option under scenario 1 equates to about 845 large salmon.

There is a >99% probability of meeting conservation requirement for the large salmon with the FSC allocation of 445 large salmon or less and a recreational fishery in 2012 as in 2011 (Table 5). The probability of meeting conservation requirement declines to less than 75% for an FSC allocation greater than 1,595 large salmon.

The expected losses of small salmon in the recreational fishery are 155 fish including 144 retained (5^{th} and 95^{th} percentiles: 70 to 277) and 11 from catch and release mortality (5^{th} and 95^{th} percentiles: 4 to 24) (Tables 4, 6). The exploitation rate on large salmon that corresponds to a 95% probability that the conservation requirement would be attained in 2012 is 27.5%. At an exploitation rate of 27.5%, the median predicted available harvest of small salmon in Margaree River for 2012 totals 271 fish (5^{th} to 95^{th} percentile 144 to 521 fish) for all fisheries.

With these expected recreational fishing losses and for the objective of not exceeding a 27.5% exploitation rate (50% risk level), the FSC allocation for small salmon corresponds to 116 fish (median value; 5^{th} to 95^{th} percentile range 0 to 195 fish). The exploitation rate is 31% with a recreational fishery in 2012 as in 2011 and an FSC allocation of 135 small salmon. With both FSC and recreational fisheries, the exploitation rate on small salmon varies from 31% to 85% over the range of FSC allocations examined (Table 6).

4.5.2 Fishery scenario 2

For a recreational catch and release fishery in October only, the expected losses from catch and release mortality are 21 large salmon and 4 small salmon (Tables 5, 6). Total losses (median value) over the range of FSC allocations examined represent exploitation rates of 12% to 53% of the total returns of large salmon.

There is a greater than 99% chance of meeting conservation requirement for large salmon for an FSC allocation of 445 large salmon or less (Table 5). For a 5% or lower risk of failing to meet the conservation requirement and with a recreational fishery open only in October for catch and release, the FSC large salmon allocation is 895 fish. The probability of meeting conservation requirement declines to less than 75% for an FSC allocation greater than 1,595 large salmon (Table 5).

For a recreational fishery in October only with mandatory catch and release of small salmon, the expected losses from catch and release mortality are 4 small salmon (median; 5^{th} to 95^{th} percentile 1 to 9 fish). At a 27.5% exploitation rate on the predicted small salmon returns, the corresponding FSC removals (after accounting for recreational fisheries losses) correspond to 267 small salmon (5^{th} to 95^{th} percentile range 262 to 270 fish). Total losses (median value) for 2012 from all fisheries represent exploitation rates of 15% to 70% over the range of small salmon FSC allocations examined (Table 6). The probabilities of meeting or exceeding the 27.5% exploitation rate objective range from 4% to 98% (Table 6) and the probabilities of meeting or exceeding the small salmon spawner objective of 582 fish decrease from 80% to 29% (Table 6).

4.5.3 Fishery scenario 3

With the recreational fishery closed, the probability of the meeting conservation requirement for large salmon is >99% with an FSC allocation of 495 large salmon or less (Table 5). At a 5% risk level of failing to meet the conservation requirement, the projected surplus to conservation requirement for 2012 is 917 large salmon. The probability of meeting the conservation requirement declines to 75% for an FSC allocation of 1,645 large salmon (Table 5). The exploitation rate on large salmon ranges from a low of 11% for an FSC allocation of 345 large salmon to 52% at an FSC allocation of 1,645 fish (Table 5).

At an exploitation rate of 27.5%, the median predicted available harvest of small salmon for 2012 is 271 fish (5^{th} to 95^{th} percentile 144 to 521 fish). At a 50% risk level, a surplus of 403 small salmon is predicted relative to the secondary objective of achieving 582 small salmon. With the recreational fishery closed, total losses from FSC fisheries only for 2012 represent exploitation rates of 15% to 69% over the range of small salmon FSC allocations examined (Table 6). The probabilities of meeting or exceeding the 27.5% exploitation rate objective range from 3% to 98% (Table 6) and the probabilities of meeting or exceeding the small salmon spawner objective of 582 fish decrease from 80% to 30% with increases in allocations (Table 6).

5. UNCERTAINTIES

Forecasted returns to the Margaree River in 2012 are very uncertain. First, the forecasts are based on the average of the estimated returns over the 1987 to 2011 time period. Over that time period, estimated returns varied annually but there is no discernible trend in abundance. As a consequence of the large annual variations in abundance seen over that time period and the uncertainties in the annual estimates, the uncertainties in the forecast for 2012 are large

(coefficient of variation of 34% for large salmon, 42% for small salmon). However, the Bayesian hierarchical model is an appropriate framework for incorporating these two levels of uncertainty. Second, assessments of annual returns during 1997 to the present are based on catch and effort data from angler logbooks and from angling licence stubs returned, adjusted by catchability coefficients estimated for the 1988 to 1996 return years. It was assumed that the catchability coefficients estimated for the earlier time period are still appropriate and that the data reported by anglers have been consistently tabulated over the entire time series.

The returns of small salmon and large salmon in a given year are very uncertain. Marine survival rates of Atlantic salmon in eastern Canada are highly variable among populations and among years, have generally declined in the past two decades, and returns of adult salmon are often unrelated to the corresponding smolt production (Chaput 2012; ICES 2012).

Further diagnostic and performance measures for the assessment and forecast model should be done. Diagnostics of interest include the fit of the model to the data using, for example, predicted recaptures at the sampling locations and in logbook angler reports, and predicted versus observed catches in logbooks and at the monitoring sites. The performance of the model should be examined via cross-validation, by predicting returns and catches in previous years which were excluded from the model and assessing these relative to estimated annual returns and catches.

Catch and harvest data in the recreational fisheries are incomplete and estimates are made by raising the reported licence stub statistics to total licence sales. It was assumed that the incidental mortality rate on caught and released salmon is 5%. This value has not been estimated from observations in the Margaree River but is within the range of values assumed in other fisheries of Gulf Region. Since most of the angling catches occur in the fall season when water temperatures are reasonably cool (< 20 °C), the 5% value is considered to be reasonable.

Harvests in the aboriginal FSC fisheries are also incomplete. In most years, DFO did not receive any reports of harvests of Atlantic salmon from the aboriginal communities. As FSC allocations increase, the control and reporting of fishing activities will become more important in the assessment of stock status and the evaluation of risks to conservation requirement of Atlantic salmon.

6. SUMMARY

Conservation requirement for rivers in the DFO Gulf Region is defined as an egg requirement to be obtained from large salmon. A secondary objective (not a conservation requirement) is also defined for small salmon to guard against size selective fishing pressure.

The median (corrected for autocorrelation) predicted return of large salmon in 2012 is 3,338 fish with a 95% probability that at least 1,953 fish may return to the Margaree in 2012. A potential surplus to conservation requirement is calculated based on a low probability (5%) of failing to meet conservation requirement in 2012. Under this precautionary approach situation of low risk to conservation requirement (5%), a surplus to conservation requirement of 917 large salmon is predicted for 2012. Fishery options with a total loss of 917 large salmon or less result in a low probability (<5%) of failing to meet conservation requirement for large salmon in 2012. This harvest level corresponds to an exploitation rate of 27.5% (median value) of the large salmon return. An alternate objective for small salmon to that in CAFSAC (1991b) is proposed and it represents a target exploitation rate (fisheries losses relative to returns) for small salmon. Managing fisheries such that a similar exploitation rate applies to all age and size groups of

salmon is consistent with principles of preventing size-selective or age-selective fishing pressures on aquatic resources. For the objective of managing for a similar exploitation rate on small salmon, total fisheries losses in 2012 could be 271 small salmon (median; 5th to 95th percentile range 144 to 521 fish).

Three management scenarios are evaluated based on varying levels of harvest and the probability of meeting conservation requirement in 2012. Scenarios are also assessed against the probability of meeting a sex ratio of one male to one female. The small salmon have biological characteristics that differ from large salmon (age and size at maturity, sex ratio) and presumably contribute genetically and ecologically to the long-term fitness of the population.

The management scenario of status quo for the recreational fishery and incremental increase of 50 large salmon in FSC allocation options (345 to 995 large salmon) result in a successive decline from almost 100% to 93% probability of meeting the conservation requirement for large salmon. The probability of meeting the conservation requirement is 93% in a scenario of a recreational catch and release fishery in the month of October combined with a FSC allocation of 1,000 large salmon. The probability of meeting the conservation requirement is reduced to 77% for large salmon when the FSC allocation increased to 1,599 large salmon (no recreational fishery).

For the objective of obtaining a one male to one female sex ratio, there is a 48% probability of meeting the 582 small salmon required under the management measures in effect in 2011. Under the scenario of FSC allocation options of 600 small salmon (scenario 2 – recreational catch and release October fishery) or 613 small salmon (scenario 3 – no recreational fishery), there are a 32% and 31% probability, respectively, of meeting this objective in 2012 but a very high probability (98%) of exceeding the target exploitation rate of 27.5%.

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Table 1. Licence sales for the Atlantic salmon recreational fishery in Nova Scotia, number of licence stubs returned to the province by anglers, percentage of licence stubs returned, estimated angling effort, catches of large salmon and small salmon, and the numbers of small salmon retained and released in the recreational fishery of the Margaree River, 1987 to 2011. A retention fishery on small salmon occurs in Margaree River. Estimated numbers of fish retained and released are shown. Licence stub data for 2011 are the extractions from the database as of August 23, 2012.

Year	License sold	License stubs returned by anglers	Percent of voluntary returns	Percent of license stubs returned	Effort (rod days)	Catch		Small salmon	
						large salmon	small salmon	retained	released
1987	7,191	6,663	34%	93%	12,773	1,847	972	822	150
1988	8,040	5,891	36%	73%	14,136	1,979	901	771	130
1989	8,615	6,138	34%	71%	13,241	1,607	574	444	130
1990	8,312	5,673	33%	68%	14,062	1,520	655	502	153
1991	6,354	4,241	28%	67%	13,407	1,808	773	575	198
1992	6,412	4,368	31%	68%	15,016	1,999	699	568	131
1993	6,798	5,726	35%	84%	15,575	1,090	769	556	213
1994	5,001	3,478	27%	70%	13,534	1,478	427	290	137
1995	4,576	3,170	31%	69%	12,336	1,091	343	205	138
1996	3,766	2,612	36%	69%	9,224	1,938	1,239	284	955
1997	3,611	2,373	34%	66%	9,827	2,105	311	195	116
1998	2,600	1,697	32%	65%	10,129	1,341	352	209	143
1999	2,461	2,023	33%	82%	7,843	808	311	197	114
2000	2,153	1,451	35%	67%	7,351	696	262	133	129
2001	1,948	1,247	26%	64%	7,521	854	364	142	222
2002	2,140	1,387	29%	65%	7,359	611	363	161	202
2003	2,068	1,164	29%	56%	7,398	1,138	327	184	143
2004	2,268	867	36%	38%	7,896	1,408	518	251	267
2005	2,330	1,536	25%	66%	9,382	1,340	418	206	212
2006	2,533	1,256	24%	50%	9,088	1,256	444	253	191
2007	2,310	1,274	25%	55%	8,675	784	341	186	155
2008	2,200	710	29%	32%	8,658	1,391	684	331	353
2009	2,394	663	25%	28%	8,274	1,023	171	50	121
2010	1,938	640	30%	33%	7,207	1,227	426	182	244
2011	2,491	816	24%	33%	7,429	2,159	579	196	383

Table 2. Estimated returns of large salmon, estimated annual catches of large salmon, estimated catch rates (catches divided by returns), estimated losses (due to catch and release fishing), exploitation rates (losses divided by returns), estimated catch in October and proportion of catch in October in the recreational fishery, 1987 to 2011.

Year	Estimated return (Median; 5th and 95th percentiles)	Estimated catch	Catch rate (Median; 5th and 95th percentiles)	Estimated losses (Median; 5th and 95th percentiles)	Exploitation rate (Median; 5th and 95th percentiles)	Catch in October	Prop. of catch in October
1987	3,575 (3,131 – 4,090)	1,847	0.52 (0.45 - 0.59)	92 (77 - 108)	0.026 (0.021 - 0.032)		
1988	3,461 (3,030 – 3,970)	1,979	0.57 (0.5 - 0.65)	99 (83 - 115)	0.029 (0.023 - 0.035)		
1989	2,900 (2,530 – 3,343)	1,607	0.55 (0.48 - 0.64)	80 (67 - 95)	0.028 (0.022 - 0.034)		
1990	2,616 (2,280 – 3,016)	1,520	0.58 (0.5 - 0.67)	76 (63 - 91)	0.029 (0.023 - 0.036)		
1991	3,237 (2,812 – 3,742)	1,808	0.56 (0.48 - 0.64)	90 (75 - 106)	0.028 (0.022 - 0.035)		
1992	3,262 (2,860 – 3,743)	1,999	0.61 (0.53 - 0.7)	100 (84 - 116)	0.031 (0.025 - 0.037)		
1993	1,829 (1,618 – 2,085)	1,090	0.60 (0.52 - 0.67)	54 (43 - 66)	0.03 (0.023 - 0.037)		
1994	2,765 (2,403 – 3,192)	1,478	0.53 (0.46 - 0.62)	74 (60 - 88)	0.027 (0.021 - 0.034)		
1995	2,077 (1,798 – 2,408)	1,091	0.53 (0.45 - 0.61)	54 (43 - 67)	0.026 (0.02 - 0.034)		
1996	4,385 (3,782 – 5,089)	1,938	0.44 (0.38 - 0.51)	97 (82 - 113)	0.022 (0.018 - 0.028)		
1997	4,790 (4,121 – 5,581)	2,105	0.44 (0.38 - 0.51)	105 (89 - 122)	0.022 (0.018 - 0.027)	859	0.41
1998	2,900 (2,491 – 3,397)	1,341	0.46 (0.39 - 0.54)	67 (54 - 80)	0.023 (0.018 - 0.029)	477	0.36
1999	2,215 (1,894 – 2,598)	808	0.36 (0.31 - 0.43)	40 (31 - 51)	0.018 (0.013 - 0.024)	328	0.41
2000	2,106 (1,783 – 2,494)	696	0.33 (0.28 - 0.39)	35 (26 - 45)	0.016 (0.012 - 0.022)	285	0.41
2001	2,422 (2,050 – 2,854)	854	0.35 (0.3 - 0.42)	43 (33 - 53)	0.018 (0.013 - 0.023)	449	0.53
2002	1,786 (1,507 – 2,119)	611	0.34 (0.29 - 0.41)	30 (22 - 40)	0.017 (0.012 - 0.023)	291	0.48
2003	3,304 (2,802 – 3,905)	1,138	0.34 (0.29 - 0.41)	57 (45 - 69)	0.017 (0.013 - 0.022)	470	0.41

Table 2 (continued).

Year	Estimated return (Median; 5th and 95th percentiles)	Estimated catch	Catch rate (Median; 5th and 95th percentiles)	Estimated losses (Median; 5th and 95th percentiles)	Exploitation rate (Median; 5th and 95th percentiles)	Catch in October	Prop. of catch in October
2004	3,779 (3,196 – 4,480)	1,408	0.37 (0.31 - 0.44)	70 (57 - 84)	0.019 (0.014 - 0.024)	551	0.39
2005	3,123 (2,672 – 3,654)	1,340	0.43 (0.37 - 0.5)	67 (54 - 80)	0.021 (0.017 - 0.027)	399	0.3
2006	3,005 (2,553 – 3,533)	1,256	0.42 (0.36 - 0.49)	63 (51 - 76)	0.021 (0.016 - 0.027)	416	0.33
2007	2,082 (1,766 – 2,464)	784	0.38 (0.32 - 0.44)	39 (30 - 49)	0.019 (0.014 - 0.025)	242	0.31
2008	3,149 (2,641 – 3,752)	1,391	0.44 (0.37 - 0.53)	69 (56 - 83)	0.022 (0.017 - 0.029)	412	0.3
2009	2,428 (2,016 – 2,910)	1,023	0.42 (0.35 - 0.51)	51 (40 - 63)	0.021 (0.015 - 0.028)	357	0.35
2010	3,243 (2,702 – 3,877)	1,227	0.38 (0.32 - 0.45)	61 (49 - 74)	0.019 (0.014 - 0.024)	189	0.15
2011	5,726 (4,837 – 6,806)	2,159	0.38 (0.32 - 0.45)	108 (91 - 125)	0.019 (0.015 - 0.024)	368	0.17

Table 3. Estimated returns of small salmon, estimated annual catches of small salmon, estimated catch rates, estimated retained, estimated proportion released, estimated losses (retained plus catch and release mortality), exploitation rates, estimated catch in October and proportion of catch in October in the recreational fishery, 1987 to 2011.

Year	Return (Median; 5th and 95th percentiles)	Estimated catch	Catch rate (Median; 5th and 95th percentiles)	Estimated retained	Prop. released	Estimated losses (Median; 5th and 95th percentiles)	Exploitation rate (Median; 5th and 95th percentiles)	Catch in October	Prop. of catch in October
1987	1,743 (1,472 – 2,106)	972	0.56 (0.46 - 0.66)	822	0.15	829 (825 - 834)	0.48 (0.39 - 0.56)		
1988	1,486 (1,247 – 1,804)	901	0.61 (0.5 - 0.72)	771	0.14	777 (774 - 782)	0.52 (0.43 - 0.62)		
1989	973 (808 – 1,189)	574	0.59 (0.48 - 0.71)	444	0.23	450 (447 - 455)	0.46 (0.38 - 0.56)		
1990	1,074 (896 – 1,312)	655	0.61 (0.5 - 0.73)	502	0.23	509 (506 - 514)	0.47 (0.39 - 0.57)		
1991	1,263 (1,050 – 1,548)	773	0.61 (0.5 - 0.74)	575	0.26	585 (580 - 590)	0.46 (0.38 - 0.56)		
1992	1,080 (904 – 1,314)	699	0.65 (0.53 - 0.77)	568	0.19	574 (571 - 579)	0.53 (0.44 - 0.64)		
1993	1,208 (1,032 – 1,442)	769	0.64 (0.53 - 0.75)	556	0.28	567 (562 - 572)	0.47 (0.39 - 0.55)		
1994	732 (607 - 898)	427	0.58 (0.48 - 0.7)	290	0.32	297 (293 - 301)	0.41 (0.33 - 0.49)		
1995	602 (495 - 743)	343	0.57 (0.46 - 0.69)	205	0.4	212 (208 - 216)	0.35 (0.28 - 0.43)		
1996	2,700 (2,209 - 3331)	1,239	0.46 (0.37 - 0.56)	284	0.77	332 (321 - 343)	0.12 (0.1 - 0.15)		
1997	630 (512 - 786)	311	0.49 (0.4 - 0.61)	195	0.37	201 (197 - 205)	0.32 (0.26 - 0.39)	65	0.21
1998	721 (582 - 900)	352	0.49 (0.39 - 0.6)	209	0.41	216 (212 - 221)	0.30 (0.24 - 0.37)	62	0.18
1999	794 (642 - 992)	311	0.39 (0.31 - 0.48)	197	0.37	203 (199 - 207)	0.26 (0.2 - 0.32)	55	0.18
2000	708 (563 - 898)	262	0.37 (0.29 - 0.47)	133	0.49	139 (136 - 144)	0.20 (0.16 - 0.25)	73	0.28
2001	937 (750 – 1,187)	364	0.39 (0.31 - 0.49)	142	0.61	153 (148 - 159)	0.16 (0.13 - 0.2)	150	0.41
2002	971 (774 – 1,229)	363	0.37 (0.3 - 0.47)	161	0.56	171 (166 - 176)	0.18 (0.14 - 0.22)	108	0.3

Table 3 (continued).

Year	Return (Median; 5th and 95th percentiles)	Estimated catch	Catch rate (Median; 5th and 95th percentiles)	Estimated retained	Prop. released	Estimated losses (Median; 5th and 95th percentiles)	Exploitation rate (Median; 5th and 95th percentiles)	Catch in October	Prop. of catch in October
2003	891 (705 – 1,133)	327	0.37 (0.29 - 0.46)	184	0.44	191 (187 - 196)	0.21 (0.17 - 0.27)	81	0.25
2004	1,254 (990 – 1,590)	518	0.41 (0.33 - 0.52)	251	0.52	264 (259 - 270)	0.21 (0.17 - 0.27)	112	0.22
2005	891 (718 – 1,111)	418	0.47 (0.38 - 0.58)	206	0.51	216 (212 - 222)	0.24 (0.19 - 0.3)	67	0.16
2006	993 (789 – 1,254)	444	0.45 (0.35 - 0.56)	253	0.43	262 (258 - 268)	0.26 (0.21 - 0.33)	78	0.18
2007	823 (656 – 1,041)	341	0.41 (0.33 - 0.52)	186	0.45	194 (190 - 199)	0.24 (0.19 - 0.3)	84	0.25
2008	1,430 (1,124 – 1,830)	684	0.48 (0.37 - 0.61)	331	0.52	349 (342 - 356)	0.24 (0.19 - 0.31)	115	0.17
2009	390 (292 - 523)	171	0.44 (0.33 - 0.59)	50	0.71	56 (52 - 60)	0.14 (0.11 - 0.19)	37	0.22
2010	1,027 (797 – 1,329)	426	0.41 (0.32 - 0.53)	182	0.57	194 (189 - 200)	0.19 (0.15 - 0.24)	49	0.12
2011	1,437 (1126 – 1,845)	590	0.40 (0.31 - 0.51)	196	0.67	215 (208 - 223)	0.15 (0.12 - 0.19)	70	0.12

Table 4. Autocorrelation values, predicted returns, and for the recreational fishery, predicted effort, predicted catch rates, predicted catches, predicted losses, and predicted exploitation rates for large salmon and small salmon in 2012, based on uncorrected or autocorrelation corrected predictions of returns in 2012. For small salmon, all the values shown are those for which 1996 is excluded from the 2012 predicted distribution.

		Large salmon		Small salmon	
	Percentiles	Uncorrected	Corrected	Uncorrected	Corrected
Effort (rod days)	Median	7,851			
	5 to 95	5,689 – 10,020			
Autocorrelation value[1]	Median	0.19		0.096	
	5 to 95	0.13 – 0.32		0.007 - 0.229	
Return	Median	2,921	3,338	940	985
	5 to 95	1,692 – 5,027	1,953 – 5,730	493 - 1794	523 - 1896
Catchability (q)	Median	$5.58 * 10^{-5}$		$6.10 * 10^{-5}$	
	5 to 95	$4.65 * 10^{-5}$ – $6.74 * 10^{-5}$		$4.71 * 10^{-5}$ – $7.93 * 10^{-5}$	
Catch rates	Median	0.36	0.35	0.38	0.38
	5 to 95	0.27 - 0.45	0.26 - 0.45	0.28 - 0.5	0.27 - 0.50
Catch	Median	1,038	1,175	357	371
	5 to 95	562 – 1,800	627 - 2035	179 - 692	184 - 717
Retained	Median	0		138	144
	5 to 95			67 - 262	70 – 277
Loss from catch and release mortality	Median	51	59	11	11
	5 to 95	26 - 93	30 -105	4 - 23	4 – 24
Total losses	Median	51	59	149	155
	5 to 95	26 - 93	30 - 105	73 - 288	76 - 300
Exploitation rate	Median	0.018	0.018	0.158	0.158
	5 to 95	0.012 – 0.024	0.012 – 0.024	0.111 – 0.213	0.107 – 0.212
Catch in October only	Median	366	414	77	79
	5 to 95	196 – 637	220 – 721	37 – 149	37 – 157
Loss from catch and release mortality in October	Median	18	21	4	4
	5 to 95	8 - 34	9 - 38	1 - 9	1 - 9

[1] For small salmon, the autocorrelation of the residuals of the time series that includes 1996 has a median value of -0.18 (5^{th} to 95^{th} percentile range -0.25 to -0.03).

Table 5. The probability of meeting or exceeding conservation for large salmon and the exploitation rate (median, fisheries losses divided by predicted return) in the Margaree River in 2012 for various fisheries scenarios. Recreational fishery scenarios are: (a) management as in 2011, (b) fishery in October only, mandatory catch and release, and (c) fishery closed.

FSC allocation	Probability (%) of meeting or exceeding 1,036 large salmon spawners			Exploitation rate (%, median)		
	Recreational fishery scenarios			Recreational fishery scenarios		
	(a)	(b)	(c)	(a)	(b)	(c)
345	99.5	99.6	99.6	12.7	11.6	10.9
395	99.3	99.4	99.5	14.3	13.1	12.5
445	99.0	99.1	99.1	15.9	14.7	14.1
495	98.8	98.9	98.9	17.4	16.3	15.7
545	98.5	98.6	98.7	19.0	17.9	17.3
595	98.1	98.3	98.4	20.6	19.5	18.8
645	97.7	97.9	98.0	22.2	21.1	20.4
695	97.3	97.5	97.6	23.8	22.6	22.0
745	96.8	97.0	97.1	25.4	24.2	23.6
795	96.2	96.4	96.6	26.9	25.8	25.2
845	95.6	96.0	96.1	28.5	27.4	26.8
895	94.7	95.2	95.3	30.1	29.0	28.4
945	93.9	94.3	94.5	31.7	30.6	29.9
995	92.9	93.5	93.8	33.3	32.1	31.5
1,045	91.8	92.3	92.6	34.9	33.7	33.1
1,095	90.6	91.2	91.5	36.4	35.3	34.7
1,145	89.4	90.0	90.4	38.0	36.9	36.3
1,195	88.1	88.8	89.1	39.6	38.5	37.9
1,245	86.8	87.4	87.8	41.2	40.1	39.4
1,295	85.4	86.2	86.5	42.8	41.6	41.0
1,345	83.7	84.7	85.1	44.4	43.2	42.6
1,395	82.1	83.1	83.6	46.0	44.8	44.2
1,445	80.6	81.4	81.9	47.5	46.4	45.8
1,495	78.9	79.8	80.5	49.1	48.0	47.4
1,545	77.0	78.0	78.7	50.7	49.6	48.9
1,595	75.1	76.4	76.9	52.3	51.1	50.5
1,645	73.1	74.4	75.0	53.9	52.7	52.1

Table 6. The estimated exploitation rate (median; fisheries losses divided by predicted return) on small salmon, the probability of meeting or exceeding a 27.5% exploitation rate, and the probability that the spawners after fisheries losses will be greater than or equal to 582 small salmon in the Margaree River in 2012 under various fisheries scenarios. Recreational fishery scenarios are: (a) management as in 2011, (b) fishery in October only, mandatory catch and release, and (c) fishery closed.

FSC allocation	Exploitation rate (%, median)			Probability (%) exploitation rate >= 27.5%			Probability (%) small salmon spawners >= 582 fish		
	Recreational fishery scenarios			Recreational fishery scenarios			Recreational fishery scenarios		
	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)
135	30.5	15.1	14.7	63.2	3.8	3.4	65.0	80.0	80.3
185	35.9	20.5	20.1	83.5	16.2	15.4	58.3	74.6	74.9
235	41.4	26.0	25.6	92.4	36.4	35.0	51.6	69.1	69.5
285	46.8	31.4	31.0	96.4	56.6	55.1	45.5	63.4	63.6
335	52.2	36.9	36.5	98.2	72.0	70.7	39.7	57.6	58.0
385	57.7	42.3	41.9	99.2	82.5	81.8	34.8	51.7	52.1
435	63.1	47.8	47.4	99.6	89.2	88.6	30.6	46.4	46.9
485	68.6	53.2	52.8	99.8	93.4	93.0	26.5	41.3	41.7
535	74.0	58.6	58.2	99.9	95.9	95.6	22.8	36.7	37.1
585	79.4	64.1	63.7	99.9	97.5	97.3	19.6	32.9	33.2
635	84.9	69.5	69.1	100.0	98.4	98.2	16.8	29.1	29.5

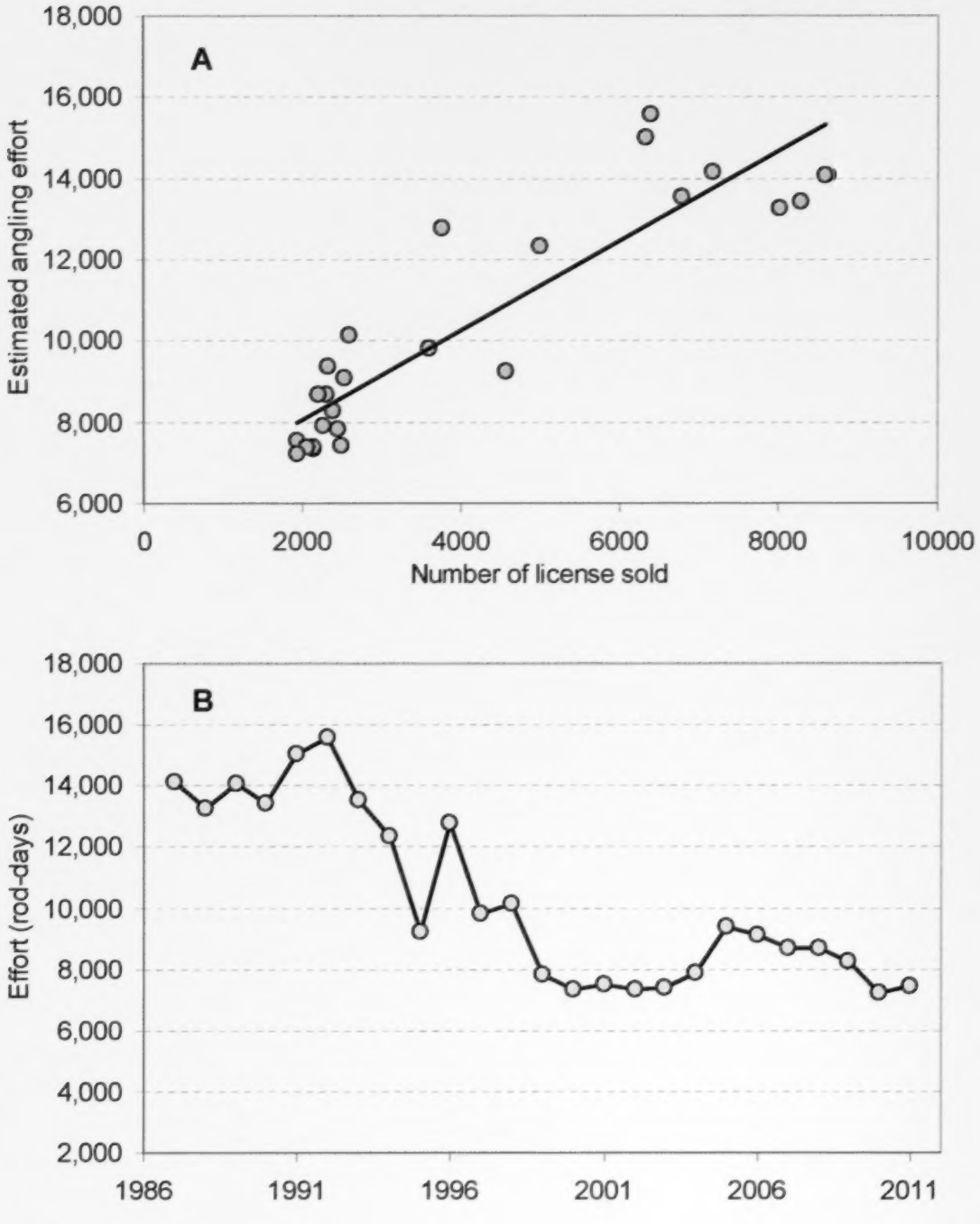


Figure 1. A) Estimated angling effort in relation to the sale of recreational Atlantic salmon licences in Nova Scotia and B) annual estimates of angling effort in Nova Scotia, 1987 to 2011.

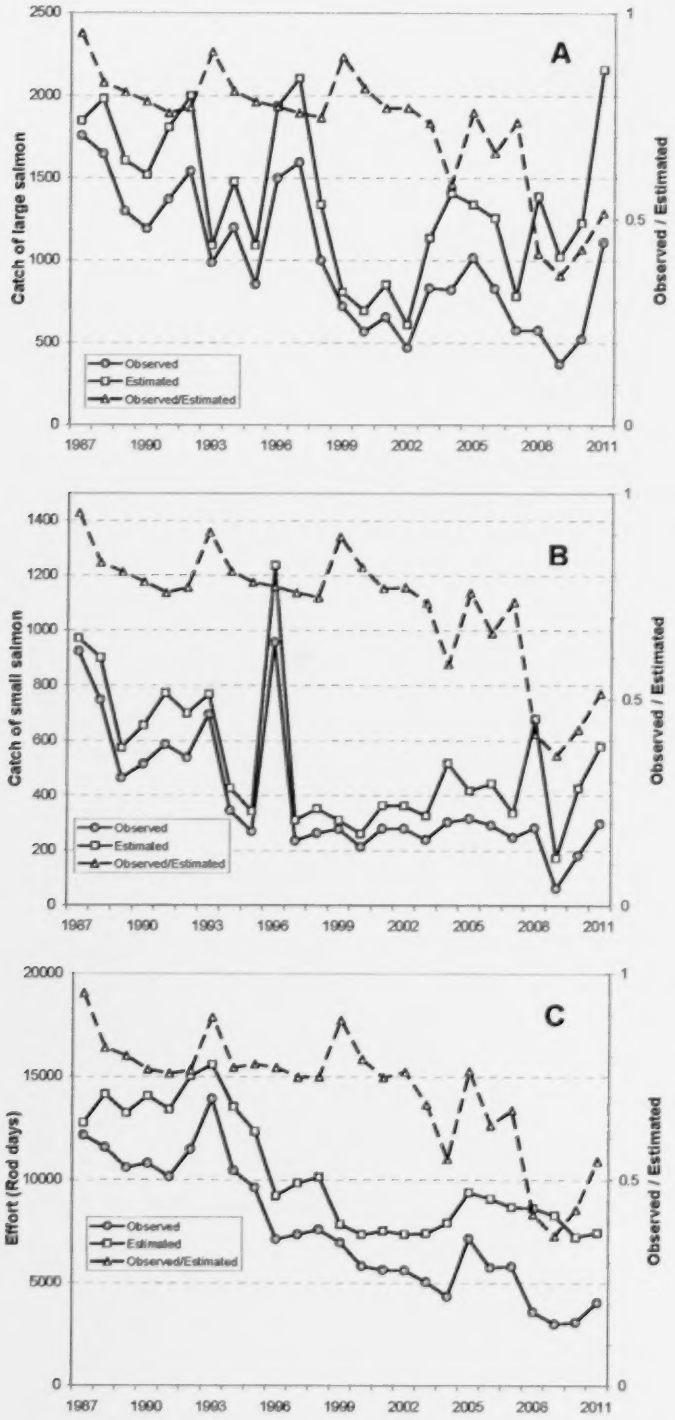


Figure 2. Observed and estimated catches of A) large salmon B) small salmon and C) effort from angler licence stubs for the Margaree River, 1987 to 2011.

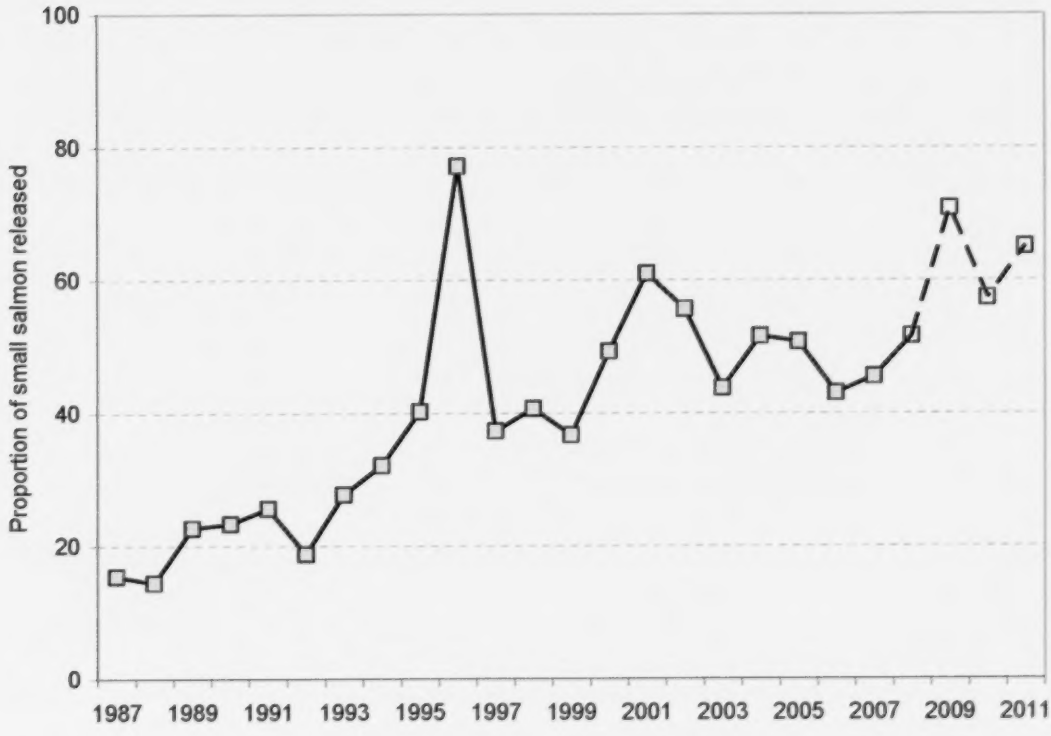


Figure 3. Proportion of small Atlantic salmon released in the Margaree River from 1987 to 2011. The grey symbol represents years when eight small salmon could be retained and the open symbol represents years when the season bag limit was reduced to four small salmon.

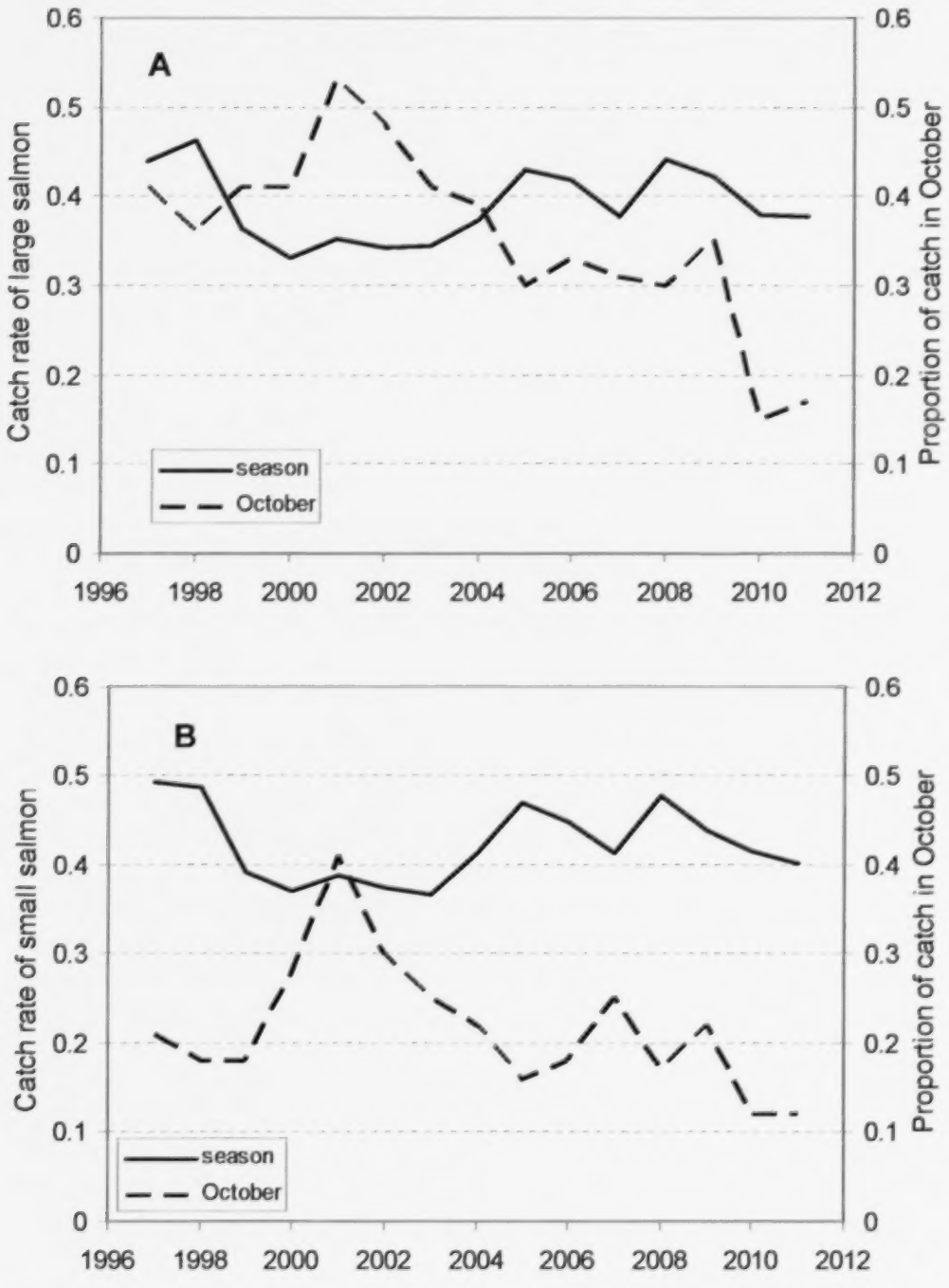


Figure 4. Estimated catch rates of A) large salmon and B) small salmon in Margaree River during the recreational fishing season (June 1 to October 31st) and the proportion of the estimated catch that occurred in October only, 1997 to 2011.

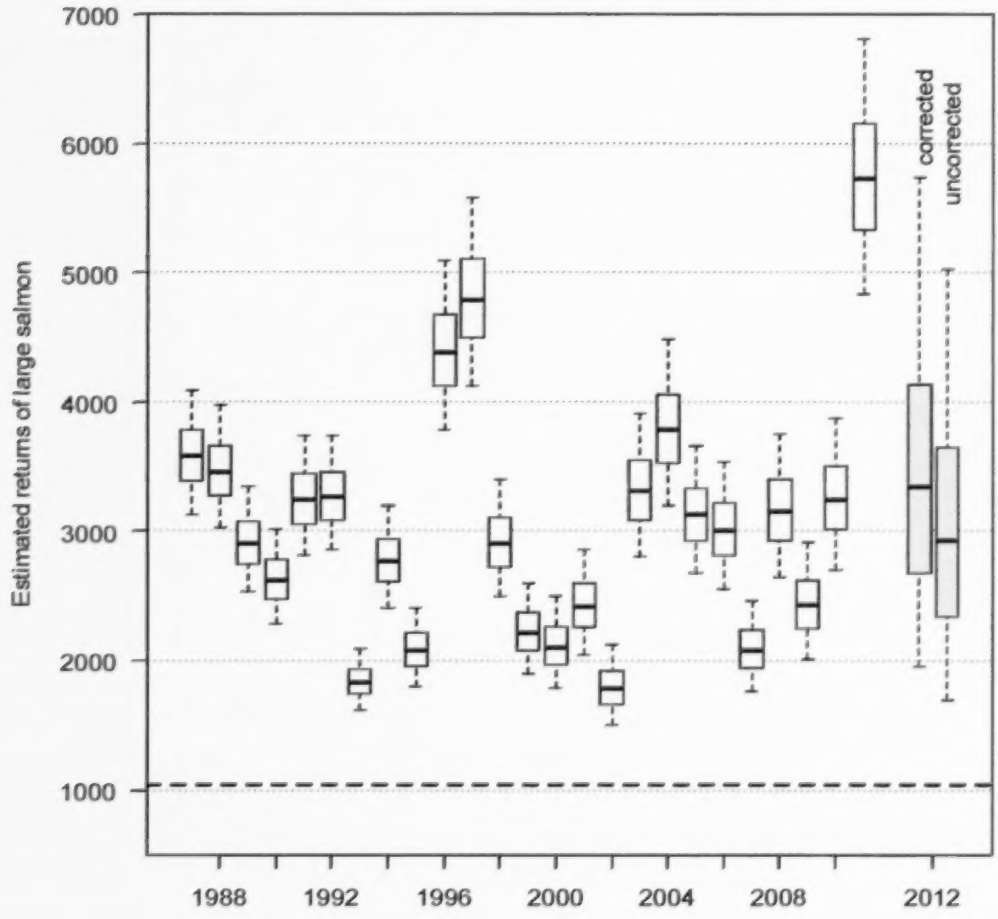


Figure 5. Posterior distributions of estimated returns of large salmon to the Margaree River for 1987 to 2011 and predicted returns for 2012. Values for 2012 (in grey shading) are predicted based on estimated returns from 1987 to 2011 and are shown for both autocorrelation corrected and uncorrected 2012 forecast. Box plots are interpreted as follows: vertical line is the 90% credibility interval range, the rectangles are the interquartile range (50% credibility interval range) and the horizontal line in the rectangle is the median value. The dash line indicates the large salmon conservation requirement of 1,036 fish.

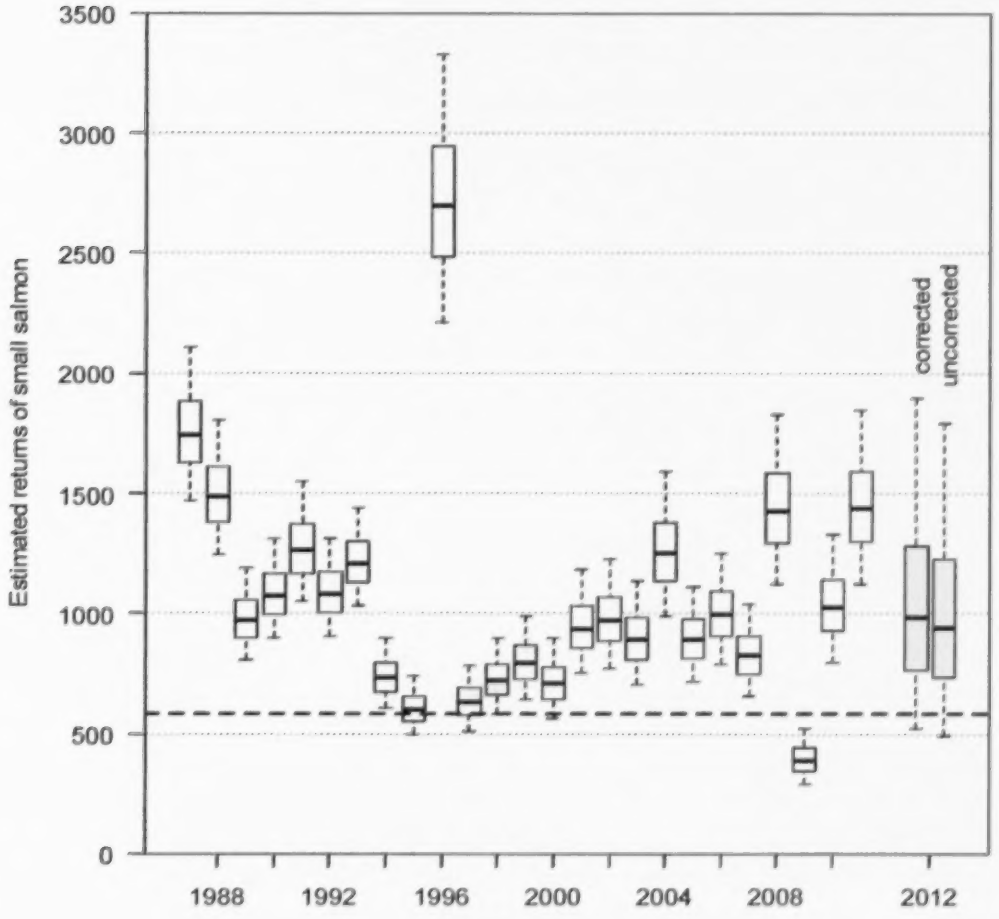


Figure 6. Posterior distributions of estimated returns of small salmon to the Margaree River for 1987 to 2011 and predicted returns for 2012. Values for 2012 are predicted based on estimated returns from 1987 to 2011 excluding 1996 and are shown for both autocorrelation corrected and uncorrected 2012 forecast. Box plots are interpreted as in Figure 5. The dash line indicates the objective of 582 small salmon for a sex ratio of 1:1 male to female.

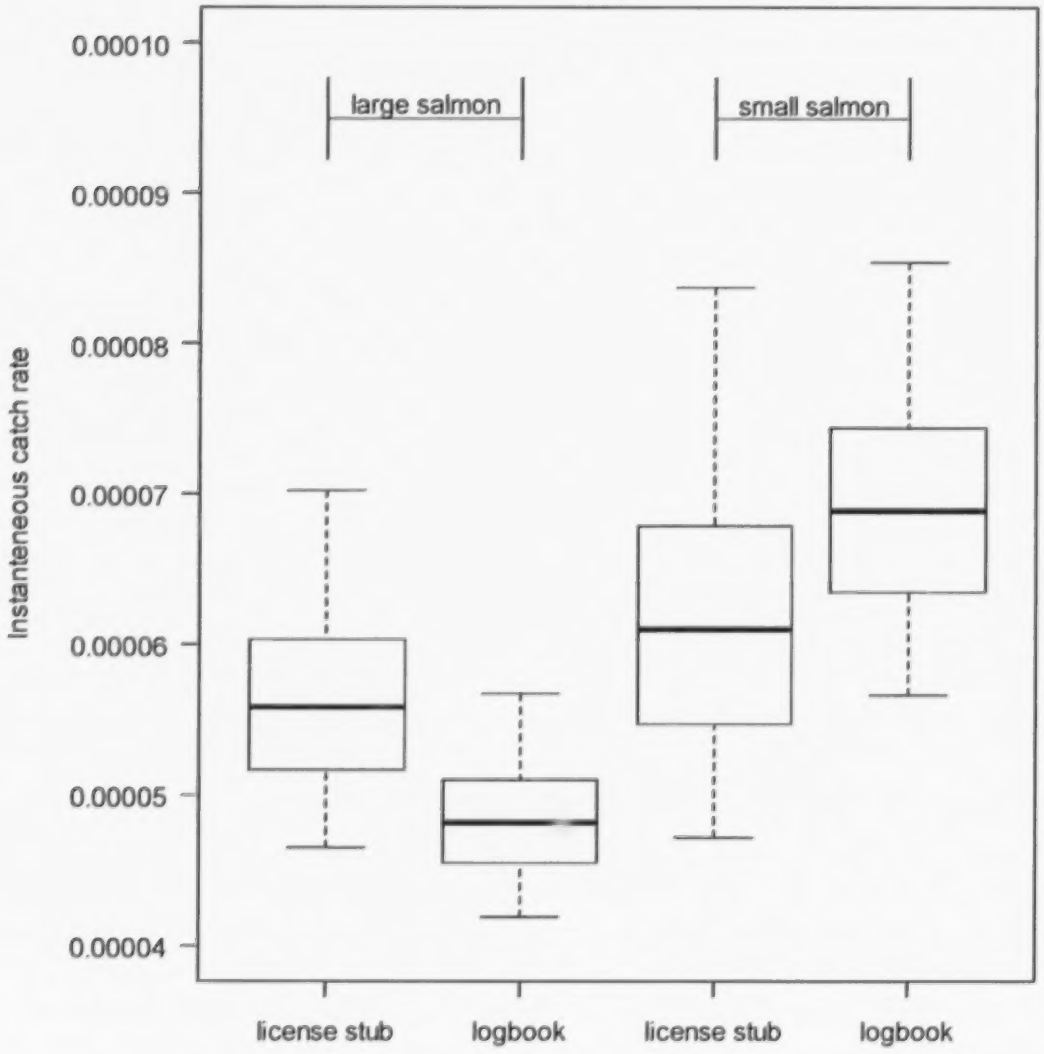


Figure 7. Posterior distributions of the instantaneous catch rate (per rod day of effort) of large salmon and small salmon for logbook anglers and based on reported catch and effort from angler license stubs. Box plots are interpreted as in Figure 5.

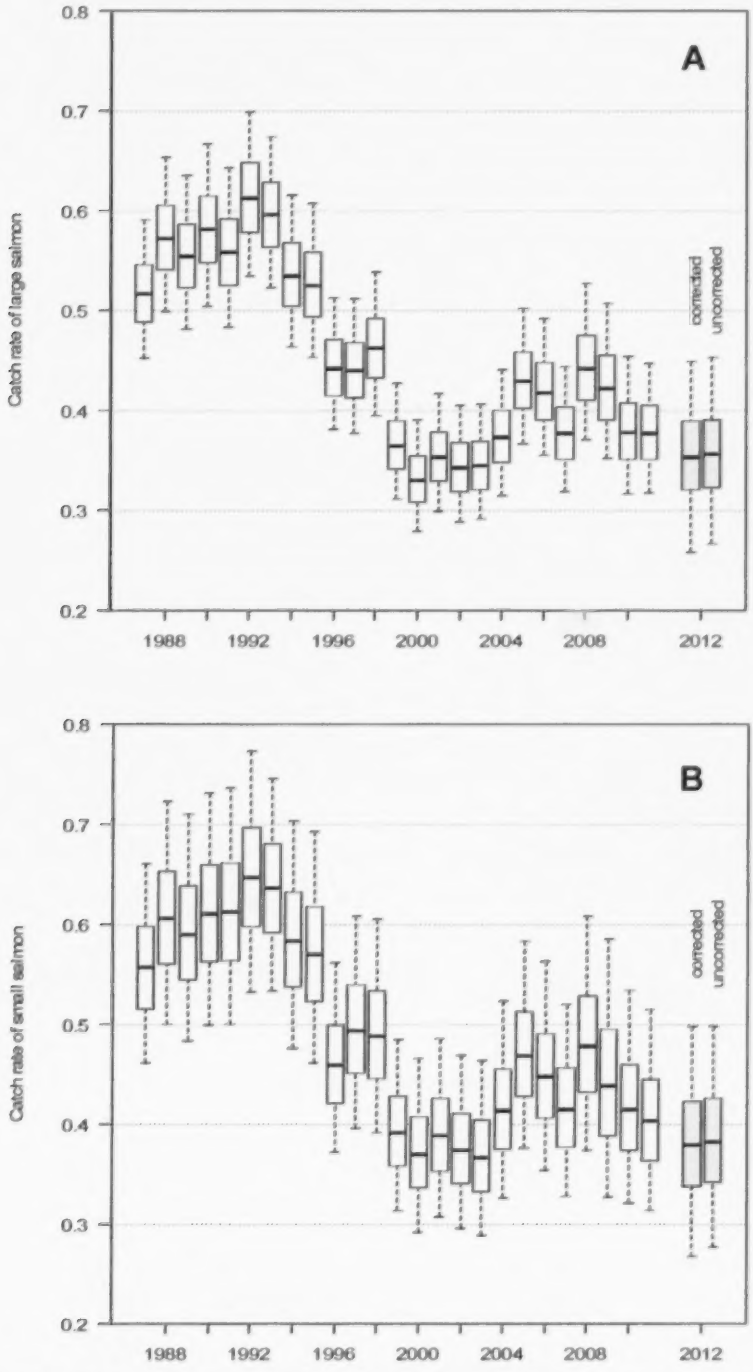


Figure 8. Posterior distributions of the estimated catch rates (proportion of returns which were angled) of A) large salmon and B) small salmon for 1987 to 2011 based on estimated catch from angler licence stubs. Values for 2012 are predicted based on autocorrelated corrected or uncorrected predicted returns and from predicted angling effort and catches in the recreational fishery for 2012. Box plots are interpreted as in Figure 5.

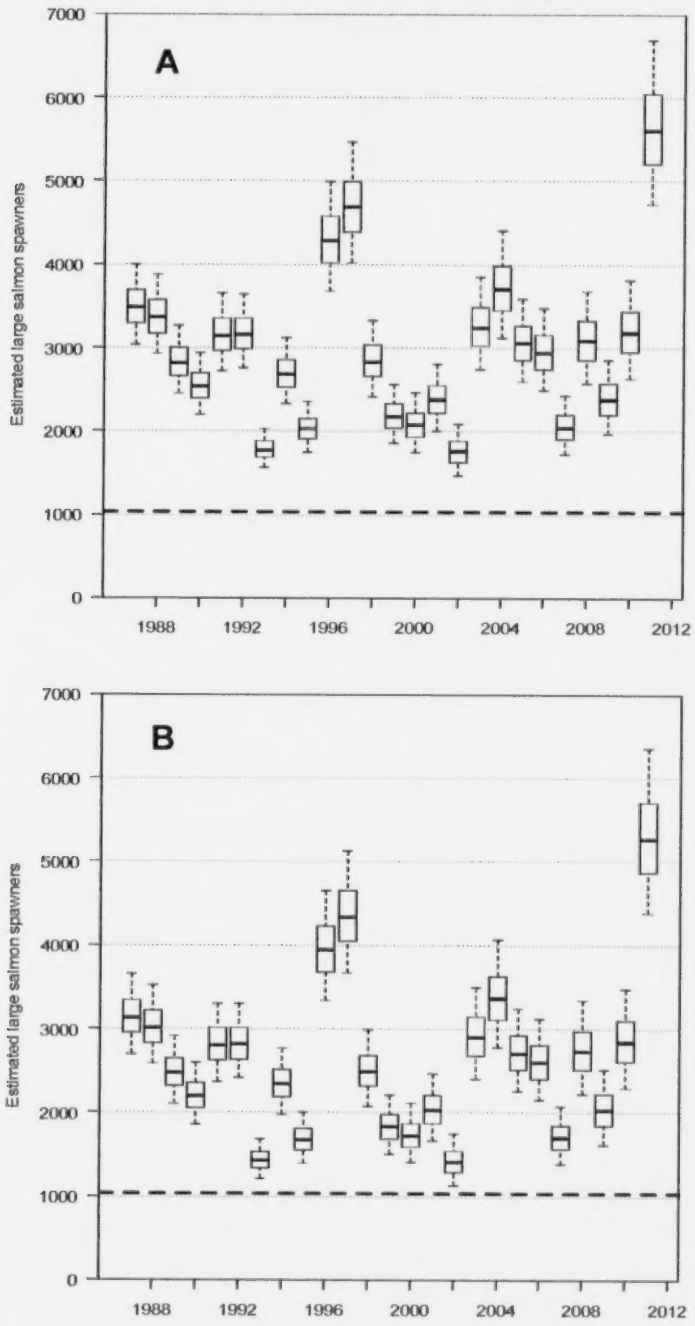


Figure 9. Estimated large salmon spawners in the Margaree River for 1987 to 2011 after accounting for A) losses in the recreational fishery only and B) after losses in all fisheries (recreational and FSC). Losses in FSC fisheries are assumed to be equal to the FSC allocation of 345 large salmon every year between 1987 and 2011. The dash horizontal line is the conservation requirement of 1,036 large salmon.

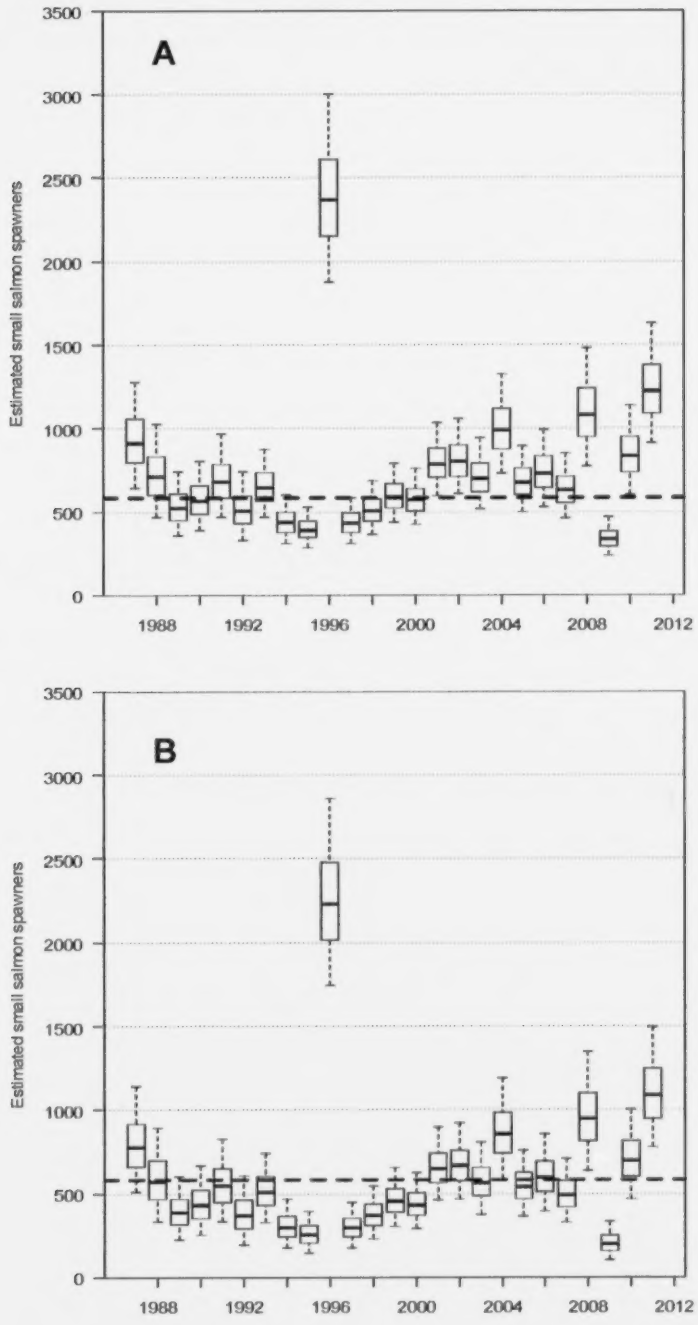


Figure 10. Estimated small salmon spawners to the Margaree River for 1987 to 2011 after accounting for A) losses in the recreational fishery only and B) after losses in all fisheries (recreational and FSC). Losses in FSC fisheries are assumed to be equal to the FSC allocation of 135 small salmon every year between 1987 and 2011. The dash horizontal line is the secondary objective of 582 small salmon for a 1:1 male to female ratio.

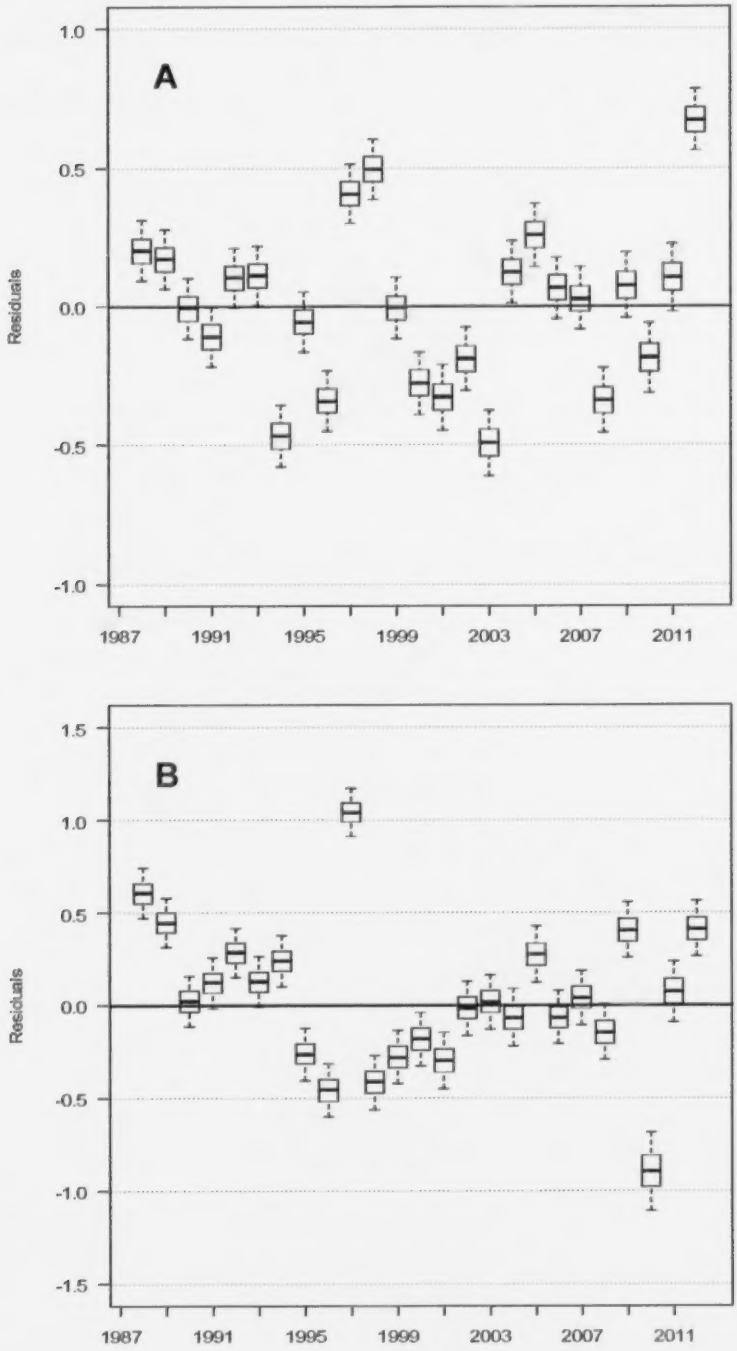


Figure 11. Log residual plots for A) large and B) small salmon in Margaree River for years 1987 to 2011. The residuals are the log value of the ratio of the annual estimates to the predicted value from the hyperdistribution estimated over all years 1987 to 2011, except for small salmon for which the 1996 value is excluded from the posterior of the hyperdistribution.

APPENDIX 1. BAYESIAN HIERARCHICAL ASSESSMENT AND RISK ANALYSIS MODEL FOR THE MARGAREE RIVER

Model

The model for estimating returns of salmon by size group was presented in Appendix Figure 1. It was structured in a Bayesian framework in which prior information of the quantities of interest were updated using observations and likelihood functions for those observations. The estimations were done separately for small and large salmon.

The quantity of interest in the context of the assessment was the return ($N_{g,y}$) of fish by size group (g = small salmon, large salmon) to the river in a given year (y). This could not be measured directly as there was no complete enumerating system on the river.

Expert opinion suggested a reasonable range for the run size to this river, based on watershed or juvenile production area and an assumed population dynamic for salmon. The conservation spawning requirement for the Margaree River was 1,036 large salmon (based on an egg deposition rate of 2.4 eggs per m² of juvenile rearing area, a total rearing area of 2.798 million m², and an average fecundity of 6,483 eggs per large salmon (Chaput et al. 1992). Maximum recruitment to the river was estimated to be less than 10,000 fish (Chaput and Jones 1992).

A hierarchical Bayesian model was developed to use the information of previous years and the current year to estimate the parameters of interests. The annual estimates of returns by size group were considered exchangeable and drawn from a common hyper-distribution. Uninformative priors were chosen for the mean and variance of the hyper-distribution; the prior for the mean was chosen uniform between 0 and 10 and the prior for the variance was chosen as proportional to $1 / \sigma^2$, with σ chosen uniform between 0 and 10.

$$\begin{aligned} N_{g,y} \mid \mu_g, \sigma_g &\sim Lognormal(\mu_g, \sigma_g^2) \\ \mu_g &\sim Uniform(0, 10) \\ \sigma_g^{-1} &\sim Uniform(0, 10) \end{aligned} \qquad (1)$$

The objective of the following model was to update this prior information using data collected from partial indicators of salmon abundance. For the Margaree River, these indices included the angling catch as reported from the license stubs, the angling catch reported from the smaller group of logbook anglers and for a few years, the catches at the directed sampling programs of the Lake O'Law counting fence and from seining of pools. These indices (data as catches or counts; C) were modelled as binomial processes with the successes (catches or counts) dependent on the number of trials (total run of fish to the river) and the probability of success (the proportion of the total run which is sampled or caught).

For each of the capture methods, this was written as:

$$C_{k,g,y} \mid N_{g,y}, \delta_{k,g,y} \sim Binomial(N_{g,y}, \delta_{k,g,y}) \qquad (2)$$

$C_{k,g,y}$ = catch

$N_{g,y}$ = abundance of salmon by size group (g) in year (y)

$\delta_{k,g,y}$ = proportion of the total run sampled by the capture method

k = capture method as

Lake O'Law fence for y = 1992 to 1996,

seining pools for y = 1993, 1995, and 1996

logbook anglers for y = 1987 to 2011, and

licence stub data for y = 1987 to 2011

g = small salmon or large salmon, and

y = year

Information about the proportion of the run sampled or captured can be estimated with mark and recapture experiments. The recaptures of previously marked fish were modelled as binomial processes. Specifically for the dedicated seining program and the monitoring at the Lake O'Law fence:

$$R_{k,g,y} \mid M_{g,y}, \delta_{k,g,y}, \varphi \sim Binomial(M'_{g,y}; \delta_{k,g,y}), \quad (3)$$

$M'_{g,y} \sim Binomial(M_{g,y}, \varphi)$

φ = probability of a marked fish being available for recapture

= 0.90 (assumed)

$\delta_{k,g,y} \sim Beta(\alpha_{k,g,y}, \beta_{k,g,y})$

Sampling from the Lake O'Law fence and seining of pools was conducted by experienced staff and all the fish were handled and examined for marks or tagging scars. To account for losses of marked fish to the recapture locations, we assumed a 10% tagging and handling mortality on fish at the trapnet.

For mark and recapture information, the number of marks which were placed on salmon and the number of recaptures were known therefore the single unknown parameter ($\delta_{i,j,k}$) was estimated. The observations were modelled as originating from a binomial process which imposes a restriction on $\delta_{i,j,k}$ to be within the closed range [0,1]. The conjugate prior distribution for a proportion was the beta distribution and uninformative priors ($\alpha = 1$, $\beta = 1$), approximately equivalent to a uniform distribution, were used. For these monitoring data, the proportions varied by sampling method, annually and between size groups.

For the logbook angling data, information was available on recaptures of previously marked fish, catch, and effort (in rod days). The proportion of the available tags recaptured by logbook anglers and the proportion of the run of salmon angled depended upon the catchability coefficient per unit of effort and the total effort. Due to the constraint imposed by modelling the catch process as binomial, the proportion of the marks or of the total return captured by logbook anglers was modelled using a negative exponential function:

$$R.Log_{g,y} \mid M_{g,y}, qLog_g, Eff.Log_y, \varphi` \sim Binomial(M'_{g,y}; \delta Log_{gy}) \quad (4)$$

$$M'_{g,y} \sim \text{Binomial}(M_{g,y}, \varphi`)$$

$\varphi`$ = probability of a marked fish being available to logbook anglers

= 0.75 (assumed)

$$\delta Log_{g,y} = 1 - \exp(-qLog_g * Eff.Log_y)$$

$$qLog_g \sim \text{Lognormal}(0, 100)$$

Detection and reporting of tags from logbook anglers was expected to be less than 100%. Losses of Carlin tags from salmon have been documented for the Margaree (Chaput et al. 1994). Over two years, Chaput et al. (1994) estimated that 70% to 90% of the tags placed at the trapnets would have been available to the anglers. For the logbook anglers, we assumed that 25% of the marks originally placed at the trapnet would not have been available, about 10% due to tagging and handling mortality and 15% for tag loss and misreporting.

We assumed that the probability of capture for one unit of effort could differ for small salmon and large salmon but would be the same over years (pooled). We imposed this restriction because of the limited number of years for which mark and recapture data were available (eight years) with which to estimate the annual variability in this parameter. We had no prior knowledge of the distribution of $qLog_g$ but had to be greater than 0 and fairly small. We modelled this prior information using a lognormal distribution, to constrain the values of $qLog_q$ to be positive, with uninformative location and scale parameters (0, 100).

With the mark and recapture data from all sampling sources, the prior information for $N_{g,y}$ was updated for the years 1988 to 1996.

For those years (1988 to 1996), the catchability coefficient for the larger community of anglers returning licence stubs was calculated. Given an estimate of $N_{g,y}$, qNS_g can be calculated by modelling the declared catches ($C.NS_{g,y}$) conditioned by the declared effort ($Eff.NS_y$) as a binomial process.

$$C.NS_{g,y} \mid N_{g,y}, qNS_g, Eff.NS_y \sim Binomial(N_{g,y}; \delta NS_{g,y}) \quad (5)$$

$$\delta NS_{g,y} = 1 - \exp(-qNS_g * Eff.NS_y)$$

Years without mark and recapture data but auxiliary data from angling

There are no mark and recapture data for 1987 or after 1996. Logbook catch and effort data are available for the entire time series, 1987 to 2011 and angling data from a larger group of anglers are available from the licence stub returns. For those years, the prior information for $N_{g,y}$ is updated using the posterior information for $qLog_g$ and qNS_g and the reported effort and catch from each angler group.

$$C_{k,g,y} \sim \text{Binomial}(N_{g,y}; \delta_{k,g,y}), \quad (6)$$

$C_{k,g,y} = C.Log_{g,y}$ = declared catch in logbooks (k)of size group g in year y

$C.NS_{g,y}$ = catch from returned licence stubs (k) of size group g in year y

$\delta_{k,g,y} = 1 - \exp(\rho_{k,g} * Eff_{k,y})$

$\rho_{k,g}$ = $qLog_g$ for logbook anglers (k) for size group g

= qNS_g for licence stub angler (k) for size group g

$Eff_{k,y}$ = $Eff.Log_y$ for logbook anglers (k) in year y, and

= $Eff.NS_y$ for licence stub angler (k).

The full model provided the structure with which to update prior information on $N_{g,y}$ for any year for which angling catches and effort data were available.

Hierarchical parameterization for returns

Since the annual returns were modelled hierarchically, the abundance of salmon by size group in a year (*y.new*) without auxiliary information (angling catches and effort) could be characterized by the hyper-distribution in equation 1.

$$N_{g,y.new} \mid \mu_g, \sigma_g^2 \sim Lognormal(\mu_g, \sigma_g^2)$$

Model adjustment, diagnostics

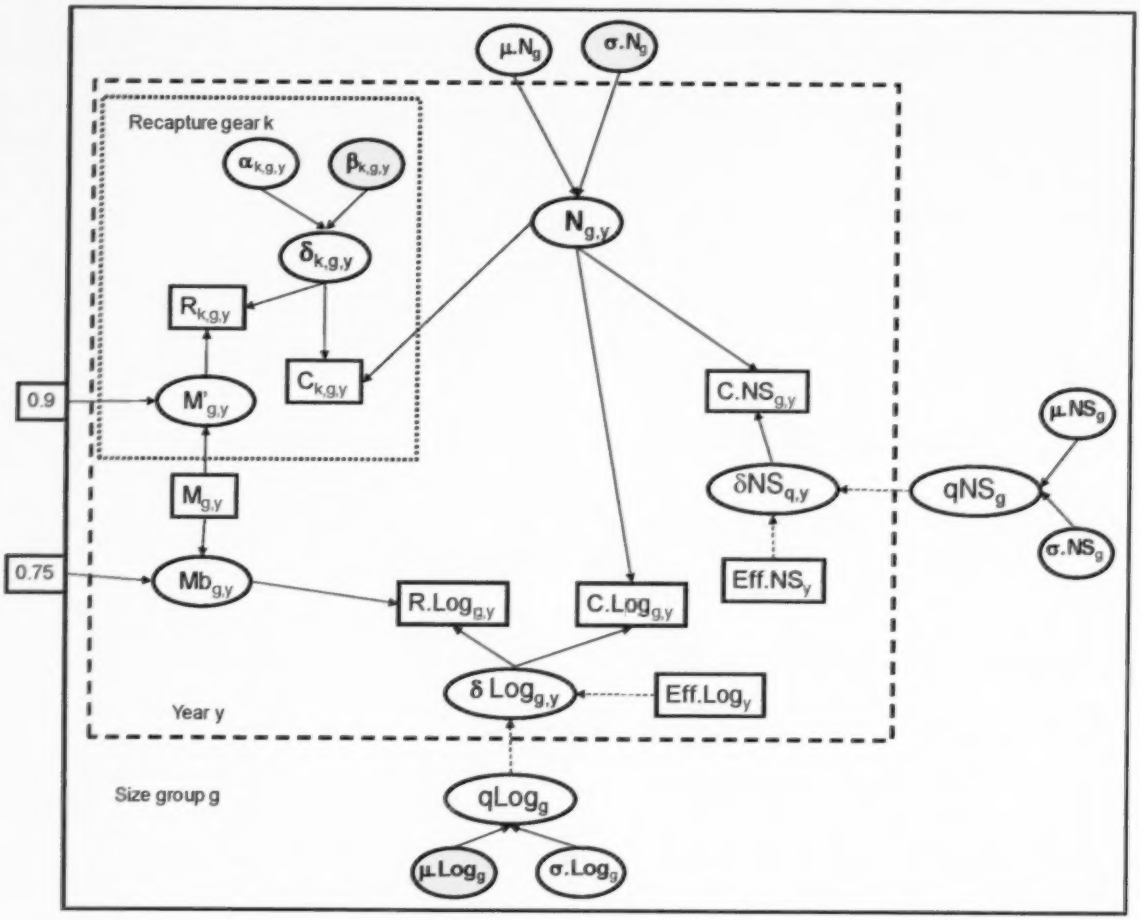
Posterior distributions of the model parameters were derived using Monte Carlo Markov Chain (MCMC) with Gibbs sampling in OpenBUGS (Spiegelhalter *et al.*, 2010). Convergence, assessed using the tools in OpenBUGS based on two chains of initial values, was achieved after 100,000 MCMC samples. A subsequent 50,000 MCMC samples were drawn and the posterior distributions were described based on every tenth retained sample, to reduce MCMC autocorrelation. Two chains of initial values were used for the MCMC sampling.

Appendix Table 1. Input data for the Bayesian model to estimate returns and the recreational fishery catchability coefficients for small salmon and large salmon in the Margaree River, 1988 to 1996. NA means no data are available.

	Number of fish marked		Recaptures of tagged fish					
			Lake O'Law fence		Seining of pools		Logbook anglers	
Year	Large	Small	Large	Small	Large	Small	Large	Small
1988	**155**	**173**	*NA*	*NA*	*NA*	*NA*	**2**	**3**
1989	**341**	**77**	*NA*	*NA*	*NA*	*NA*	**1**	*NA*
1990	**280**	**155**	*NA*	*NA*	*NA*	*NA*	**2**	**2**
1991	**198**	**163**	*NA*	*NA*	*NA*	*NA*	**4**	**6**
1992	**818**	**219**	**5**	**2**	*NA*	*NA*	**20**	**5**
1993	**334**	**229**	**4**	**3**	**6**	**1**	**11**	**11**
1994	**418**	**104**	**9**	**5**	*NA*	*NA*	**14**	**2**
1995	**369**	**123**	**10**	**7**	**18**	**1**	**7**	**2**
1996	**465**	**297**	**5**	**10**	**19**	*NA*	**17**	**20**

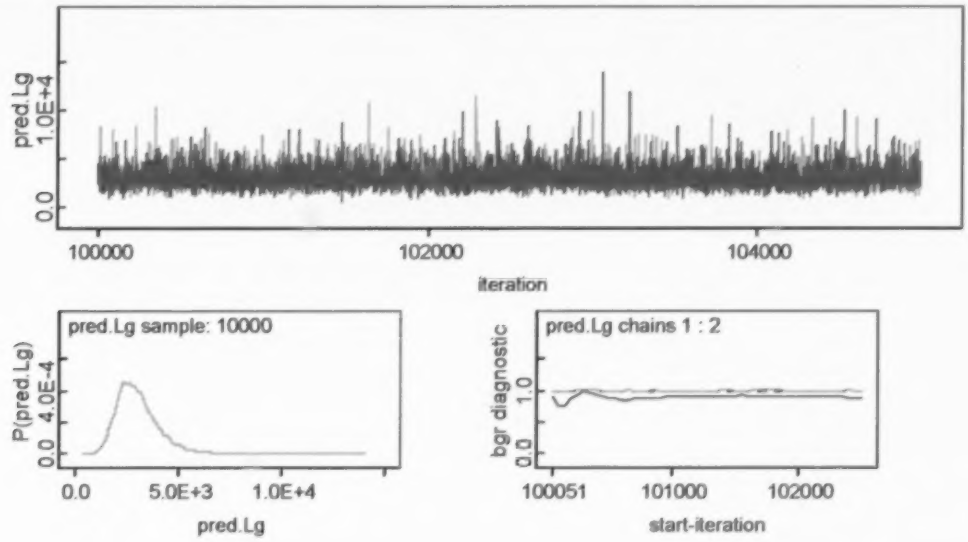
Appendix Table 2. Catches of small salmon and large salmon at the monitoring facilities, by logbook anglers, and as reported from angling license stubs, 1987 to 2011. Effort for logbook and license stub are in rod days. License stub data are the observed values, uncorrected for partial reports. NA means no data are available. Licence stub data for 2011 are the extractions from the database as of August 23, 2012.

	Catch (marked and unmarked)						Reported catch License stub data		Reported effort (rod days)	
	Lake O'Law fence		Seining of pools		Logbook anglers					
Year	Large	Small	Large	Small	Large	Small	Large	Small	Logbooks	License stubs
1987	*NA*	*NA*	*NA*	*NA*	**53**	**13**	**1,757**	**925**	**254**	**12,165**
1988	*NA*	*NA*	*NA*	*NA*	**117**	**80**	**1,645**	**749**	**674**	**11,579**
1989	*NA*	*NA*	*NA*	*NA*	**89**	**44**	**1,298**	**464**	**684**	**10,594**
1990	*NA*	*NA*	*NA*	*NA*	**82**	**66**	**1,193**	**514**	**797**	**10,792**
1991	*NA*	*NA*	*NA*	*NA*	**168**	**63**	**1,370**	**586**	**764**	**10,146**
1992	**42**	**14**	*NA*	*NA*	**136**	**74**	**1,541**	**539**	**851**	**11,483**
1993	**54**	**26**	**48**	**19**	**67**	**59**	**987**	**696**	**842**	**13,920**
1994	**86**	*NA*	*NA*	*NA*	**107**	**23**	**1,198**	**346**	**526**	**10,450**
1995	**67**	**21**	**58**	**9**	**66**	**18**	**856**	**269**	**496**	**9,617**
1996	**62**	**79**	**87**	*NA*	**173**	**206**	**1,499**	**958**	**1,191**	**7,119**
1997	*NA*	*NA*	*NA*	*NA*	**264**	**29**	**1,595**	**236**	**1,042**	**7,349**
1998	*NA*	*NA*	*NA*	*NA*	**115**	**44**	**1,001**	**263**	**817**	**7,591**
1999	*NA*	*NA*	*NA*	*NA*	**53**	**29**	**722**	**278**	**658**	**6,951**
2000	*NA*	*NA*	*NA*	*NA*	**78**	**24**	**569**	**214**	**605**	**5,822**
2001	*NA*	*NA*	*NA*	*NA*	**53**	**23**	**657**	**280**	**531**	**5,620**
2002	*NA*	*NA*	*NA*	*NA*	**52**	**37**	**471**	**280**	**534**	**5,604**
2003	*NA*	*NA*	*NA*	*NA*	**47**	**24**	**834**	**240**	**477**	**5,047**
2004	*NA*	*NA*	*NA*	*NA*	**82**	**31**	**823**	**303**	**504**	**4,343**
2005	*NA*	*NA*	*NA*	*NA*	**84**	**25**	**1,017**	**317**	**457**	**7,156**
2006	*NA*	*NA*	*NA*	*NA*	**53**	**30**	**830**	**293**	**424**	**5,745**
2007	*NA*	*NA*	*NA*	*NA*	**27**	**13**	**577**	**248**	**321**	**5,796**
2008	*NA*	*NA*	*NA*	*NA*	**48**	**37**	**578**	**283**	**360**	**3,588**
2009	*NA*	*NA*	*NA*	*NA*	**33**	**3**	**372**	**63**	**269**	**3,006**
2010	*NA*	*NA*	*NA*	*NA*	**33**	**15**	**525**	**182**	**297**	**3,084**
2011	*NA*	*NA*	*NA*	*NA*	**103**	**38**	**1111**	**298**	**137**	**4,046**

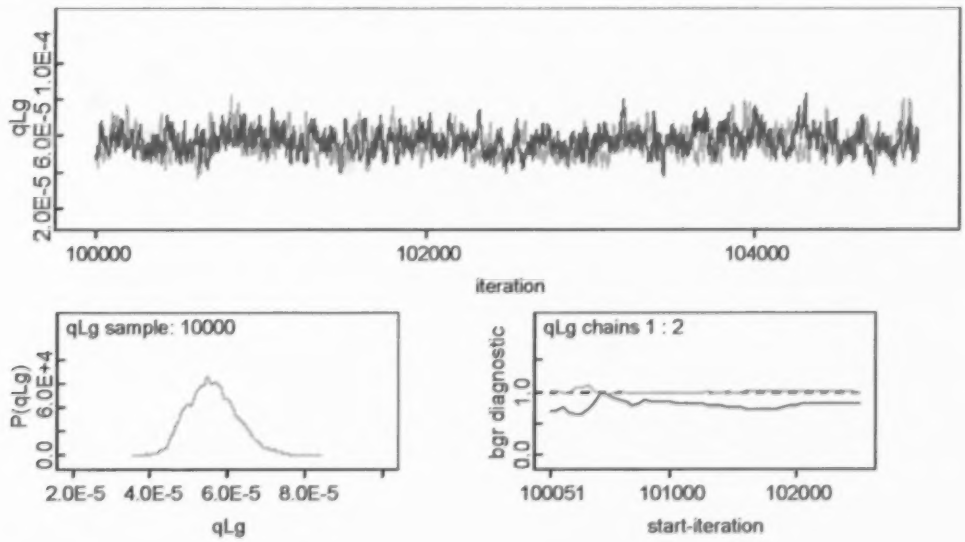


Appendix Figure 1. Directed Acyclic Graph of the processes linking the parameters and the observations. Size group (g) are small salmon (< 63 cm fork length) and large salmon (>= 63 cm fork length). Years (y) are 1987 to 2011. Recapture gear (k) include Lake O'Law fence, and seining of pools. Labels within rectangles are the data or assumptions. Labels in ellipses are latent variables, priors, or parameters to be estimated. Solid arrows designate stochastic links, dashed arrows are deterministic links.

Predicted return of large salmon



Predicted catchability coefficient for large salmon



Appendix Figure 2. Diagnostics for assessing convergence of the Bayesian hierarchical model. The history of the MCMC draws from the posterior distribution and the convergence plot are shown. The parameters selected are: predicted large salmon return for 2012 and the instantaneous catch rate of large salmon for licence stub data.

APPENDIX 2. OPENBUGS CODE FOR THE MARGAREE ASSESSMENT AND RISK ANALYSIS MODEL.

```
Model {
# hyperparameters for estimated returns by size group
mu.Lg ~ dunif(0,10)
sigma.Lg ~ dunif(0,10)
tau.Lg <- pow(sigma.Lg,-2)
pred.Lg ~ dlnorm(mu.Lg, tau.Lg)
mu.Sm ~ dunif(0,10)
sigma.Sm ~ dunif(0,10)
tau.Sm <- pow(sigma.Sm,-2)
pred.Sm ~ dlnorm(mu.Sm, tau.Sm)

for (i in 1:y){
        Lga[i] ~ dlnorm(mu.Lg, tau.Lg)
        Lg[i] <-round(Lga[i])
        res.Lg[i] <- log(Lg[i]) - mu.Lg
        res.Lg.sq[i] <- pow(res.Lg[i],2)
        res.Sm[i] <- log(Sm[i]) - mu.Sm
        res.Sm.sq[i] <- pow(res.Sm[i],2)
}

for (i in 1:8){
        Sma[i] ~ dlnorm(mu.Sm, tau.Sm)
        Sm[i] <-round(Sma[i])
        }

# for year 1996 small salmon excluded from the exchangeable assumption
Sma[9]~dunif(100,20000)
Sm[9] <- round(Sma[9])

for (i in 10:y){
        Sma[i] ~ dlnorm(mu.Sm, tau.Sm)
        Sm[i] <-round(Sma[i])
}

for (i in 1:9)  {
# marks available for capture, 10% mortality rate
        MLga[i]~dbin(0.9,MLg[i])
        MSma[i]~dbin(0.9,MSm[i])
# tags available for logbook reports; apply a 0.75 correction factor
        MLgb[i]~dbin(0.75,MLg[i])
        MSmb[i]~dbin(0.75,MSm[i])

# recapture of marked fish and catch at LOL fence
        RLgOLaw[i]~dbin(LgOLaw[i], MLga[i])
        RSmOLaw[i]~dbin(SmOLaw[i], MSma[i])
        CatLgOLaw[i]~dbin(LgOLaw[i], Lg[i])
        CatSmOLaw[i]~dbin(SmOLaw[i], Sm[i])
        LgOLaw[i]~dbeta(1,1)
        SmOLaw[i]~dbeta(1,1)

# recapture of marked fish and catch by seining
        RLgSeine[i]~dbin(LgSeine[i], MLga[i])
```

```
        RSmSeine[i]~dbin(SmSeine[i], MSma[i])
        CatLgSeine[i]~dbin(LgSeine[i], Lg[i])
        CatSmSeine[i]~dbin(SmSeine[i], Sm[i])
        LgSeine[i]~dbeta(1,1)
        SmSeine[i]~dbeta(1,1)

# recapture and catch in logbooks
# exploit. rate is a function of the instanteneous catchability and the effort
        RLgLog[i]~dbin(ERLgLog[i], MLgb[i])
        ERLgLog[i] <- (1 - exp(-qLgLog * RodsLog[i]))
        CatLgLog[i]~dbin(ERLgLog[i],  Lg[i])
        RSmLog[i]~dbin(ERSmLog[i], MSmb[i])
        ERSmLog[i] <- (1 - exp(-qSmLog * RodsLog[i]))
        CatSmLog[i]~dbin(ERSmLog[i], Sm[i])

# catch and effort from license stubs returns
        AngLg[i] ~ dbin(ERLg[i], Lg[i])
        ERLg[i] <- (1 - exp(-qLg * Effort[i]))
        AngSm[i] ~ dbin(ERSm[i], Sm[i])
        ERSm[i] <-  (1 - exp(-qSm * Effort[i]))
}

#priors
qLgLog~dlnorm(0, 0.01)
qSmLog~dlnorm(0,0.01)
qLg ~ dlnorm(0,0.01)
qSm~dlnorm(0.01,0.01)

# cut function used to preclude updating distributions for years without mark and recapture data
qLg.cut<-cut(qLg)
qSm.cut<-cut(qSm)
qLgLog.cut<-cut(qLgLog)
qSmLog.cut<-cut(qSmLog)

#for Margaree data after M-R experiment to predict returns the subsequent years
# series order, 10 = 1987, 11 = 1997 to 25 = 2011
for (i in 10:y) {
# catch and effort from license stubs returns
        AngLg[i] ~ dbin(ERLg[i], Lg[i])
        ERLg[i] <- (1 - exp(-qLg.cut * Effort[i]))
        AngSm[i] ~ dbin(ERSm[i], Sm[i])
        ERSm[i] <-  (1 - exp(-qSm.cut * Effort[i]))
# catch and effort from logbooks
        CatLgLog[i]~dbin(ERLgLog[i],  Lg[i])
        ERLgLog[i] <- (1 - exp(-qLgLog.cut * RodsLog[i]))
        CatSmLog[i]~dbin(ERSmLog[i], Sm[i])
        ERSmLog[i] <- (1 - exp(-qSmLog.cut * RodsLog[i]))
}

# autocorrelation analysis hilborn and walters p 281
# 87 to 88 residuals
  hw.xy.Lg[1] <- res.Lg[10] * res.Lg[1]
  hw.xy.Sm[1] <- res.Sm[10] * res.Sm[1]
# 88 to 96 residual comparisons
 for (i in 2:9){
  hw.xy.Lg[i] <- res.Lg[i-1] * res.Lg[i]
  hw.xy.Sm[i] <- res.Sm[i-1] * res.Sm[i]  }
```

```
# 96 to 97 residual
  hw.xy.Lg[10] <- res.Lg[9] * res.Lg[11]
  hw.xy.Sm[10] <- res.Sm[9] * res.Sm[11]
# 97 to 2011
 for (i in 11:24){
  hw.xy.Lg[i] <- res.Lg[i] * res.Lg[i+1]
  hw.xy.Sm[i] <- res.Sm[i] * res.Sm[i+1]  }

  hw.num.Lg <- sum(hw.xy.Lg[])
  auto.Lg <- ((y-1)/(y-1-1))*hw.num.Lg / sum(res.Lg.sq[])
  hw.num.Sm <- sum(hw.xy.Sm[])
  auto.Sm <- ((y-1)/(y-1-1))*hw.num.Sm / sum(res.Sm.sq[])

#without 96 for small
# 87 to 88 residuals
  hw.xy.Sm96[1] <- res.Sm[10] * res.Sm[1]
# 88 to 96 residual comparisons
 for (i in 2:8){
  hw.xy.Sm96[i] <- res.Sm[i-1] * res.Sm[i]  }
# 97 to 2011
 for (i in 9:22){
  hw.xy.Sm96[i] <- res.Sm[i+2] * res.Sm[i+3]  }

hw.num.Sm96 <- sum(hw.xy.Sm96[])
resSmsq1 <- sum(res.Sm.sq[1:8])
resSmsq2 <- sum(res.Sm.sq[10:25])
  auto.Sm96 <- ((y-2)/(y-1-2))*hw.num.Sm96 / (resSmsq1+resSmsq2)

#autocorrelated corrected prediction for 2012
log(pred.Lg.2012) <- mu.Lg + eps.Lg
eps.Lg <- auto.Lg*res.Lg[y] + w.Lg
w.Lg ~ dnorm(0, tau.Lg2012)
tau.Lg2012 <- 1 / (1-pow(auto.Lg, 2)) * tau.Lg

log(pred.Sm96.2012) <- mu.Sm + eps.Sm
eps.Sm <- auto.Sm96*res.Sm[y] + w.Sm
w.Sm ~ dnorm(0, tau.Sm2012)
tau.Sm2012 <- 1 / (1-pow(auto.Sm96, 2)) * tau.Sm

Lg.2012 <- round(pred.Lg.2012)
Sm.2012 <- round(pred.Sm96.2012)

# predicted values for 2012 not autocorrelation corrected
#Lg.2012 <- round(pred.Lg)
#Sm.2012 <- round(pred.Sm)

# estimating catch rates and losses from estimated stub catches
for (i in 1:y) {
Expl.Lg[i] <- LgRel[i]/Lg[i]
Loss.Lg[i] ~ dbin(0.05, LgRel[i])
Expl.Sm[i] <- SmCatch[i] / Sm[i]
Loss.SmRel[i] ~ dbin(0.05, SmRel[i])
Loss.Sm[i] <- Loss.SmRel[i] + SmRet[i]
}
pred.Expl.Lg <- mean(Expl.Lg[])
pred.Expl.Sm <- mean(Expl.Sm[])
```

```
# proportion small released since tags reduced from 8 to 4, in 2008
for (i in 1:4) {
pSmRet[i] ~ dbeta(SmRet[y-i-1], SmRel[y-i-1])
}
pred.pSmRet <- mean(pSmRet[])

# coding for doing the risk analysis
# estimation of losses and spawners
for (i in 1:25) {
CRmort.Lg[i] ~ dbin(0.05, LgRel[i])
Spaw.LgRec[i] <- Lg[i]-CRmort.Lg[i]
Spaw.LgFSC[i] <- Lg[i]-345
Spaw.LgTotal[i] <- Lg[i]-CRmort.Lg[i] - 345

CRmort.Sm[i] ~ dbin(0.05, SmRel[i])
Spaw.SmRec[i] <- Sm[i]-CRmort.Sm[i]- SmRet[i]
Spaw.SmFSC[i] <- Sm[i]-135
Spaw.SmTotal[i] <- Sm[i]-CRmort.Sm[i] - SmRet[i]-135
}

#management measures changed in 2008 with a reduction in seasonal bag limit from 8 to 4 grisle so the
# prop of small retained and released is calculated based on last four years
# predicted effort for 2012 is also based on the effort estimated in 2008 to 2011
# effort for 2012 is modelled as a t-distribution with 4 degrees of freedom
for (i in 1:4) {
        p.Sm.Ret[i] <- SmRet[25-(i-1)] / SmCatch[25-(i-1)]
        p.Sm.Released[i] <- SmRel[25-(i-1)] / SmCatch[25-(i-1)]
        EstRods[25-(i-1)] ~ dt(mu.eff, tau.eff, 4)
        }
        mu.eff ~ dlnorm(0,0.01)
        tau.eff ~ dgamma(0.01, 0.01)

# predicting proportion of catch that would occur in October
for (i in 1:15) {
        Sm.preOct[i] <- EstSmseason[i] - SmOct[i]
        Lg.preOct[i] <- EstLgseason[i] - LgOct[i]
        p.Sm.Oct[i] ~ dbeta(SmOct[i], Sm.preOct[i])
        p.Lg.Oct[i] ~ dbeta(LgOct[i], Lg.preOct[i])
}

E.rods <- mean(EstRodsseason[])
E.smret <- mean(EstSmRetseason[])
E.smrel <- mean(EstSmReleasedseason[])
E.smretoct <- mean(SmRetOct[])
E.smreloct <- mean(SmRelOct[])
E.smrodoct <- mean(EffortOct[])

# estimates of loss rates, called exploitation rates in res doc and SSR
for (i in 1:25) {
x[i]<-CRmort.Lg[i]/Lg[i]
z[i]<-(Loss.SmRel[i] + SmRet[i])/Sm[i]
}
# predicted values for the recreational fishery in 2012
EstRods.2012 ~dt(mu.eff, tau.eff, 4)
ER.Sm.2012 <- (1 - exp(-qSm.cut * EstRods.2012))
ER.Lg.2012 <- (1 - exp(-qLg.cut * EstRods.2012))
C.Sm.2012 ~ dbin(ER.Sm.2012, Sm.2012)
```

```
C.Lg.2012 ~ dbin(ER.Lg.2012, Lg.2012)
p.Sm.Ret.2012 <- mean(p.Sm.Ret[])
p.Sm.Rel.2012 <- 1 - p.Sm.Ret.2012
pOct.Sm <- mean(p.Sm.Oct[])
pOct.Lg <- mean(p.Lg.Oct[])
C.Ret.Sm.2012 ~ dbin(p.Sm.Ret.2012, C.Sm.2012)
C.Rel.Sm.2012 <- C.Sm.2012 - C.Ret.Sm.2012
C.Sm.Oct.2012 ~ dbin(pOct.Sm, C.Sm.2012)
C.Lg.Oct.2012 ~ dbin(pOct.Lg, C.Lg.2012)
CRmort.Lg.2012 ~ dbin(0.05, C.Lg.2012)
CRmort.Sm.2012 ~ dbin(0.05, C.Rel.Sm.2012)
CRmort.Lg.Oct.2012 ~ dbin(0.05, C.Lg.Oct.2012)
CRmort.Sm.Oct.2012 ~ dbin(0.05, C.Sm.Oct.2012)
Loss.Rec.Sm.2012 <- CRmort.Sm.2012 + C.Ret.Sm.2012
x2012 <- CRmort.Lg.2012/Lg.2012
z2012 <- (CRmort.Sm.2012 + C.Ret.Sm.2012) / Sm.2012
Sp.Lg.2012.Sport <- Lg.2012 - CRmort.Lg.2012
Cons.Lg.Sport <- Sp.Lg.2012.Sport -1036

#Attainement of Conservation; step assigns a 1 to values >= 0
p.ConsLg.Sport <- step(Cons.Lg.Sport)
Sp.Sm.2012.Sport <- Sm.2012 - Loss.Rec.Sm.2012
Cons.Sm.Sport <- Sp.Sm.2012.Sport -582
p.ConsSm.Sport <- step(Cons.Sm.Sport)

Sp.Lg.Oct.2012.Sport <- Lg.2012 - CRmort.Lg.Oct.2012
Cons.Lg.Oct.Sport <- Sp.Lg.Oct.2012.Sport -1036
p.ConsLg.Oct.Sport <- step(Cons.Lg.Oct.Sport)
Sp.Sm.Oct.2012.Sport <- Sm.2012 - CRmort.Sm.Oct.2012
Cons.Sm.Oct.Sport <- Sp.Sm.Oct.2012.Sport -582
p.ConsSm.Oct.Sport <- step(Cons.Sm.Oct.Sport)

#Scenarios
#Scenario 1: Rec et FSC (345 to 995 by 50 large)
for (i in 1: 14){
Sc1.Sp.Lg[i,1] <- Lg.2012 - CRmort.Lg.2012 - (345 + (i-1)*50)
Sc1.Cons.Lg[i,1] <- Sc1.Sp.Lg[i,1] - 1036
Sc1.pCons.Lg[i,1] <- step(Sc1.Cons.Lg[i,1])
Sc1.Sp.Lg[i,2] <- Lg.2012 - (345 + (i-1)*50)
Sc1.Cons.Lg[i,2] <- Sc1.Sp.Lg[i,2] - 1036
Sc1.pCons.Lg[i,2] <- step(Sc1.Cons.Lg[i,2])
Sc1.ERLg[i,1] <- 1 - (Sc1.Sp.Lg[i,1]/Lg.2012)
Sc1.ERLg[i,2] <- 1 - (Sc1.Sp.Lg[i,2]/Lg.2012)
}
# also 1599 large
Sc1.Sp.Lg[15,1] <- Lg.2012 - CRmort.Lg.2012 - 1599
Sc1.Cons.Lg[15,1] <- Sc1.Sp.Lg[15,1] - 1036
Sc1.pCons.Lg[15,1] <- step(Sc1.Cons.Lg[15,1])
Sc1.Sp.Lg[15,2] <- Lg.2012 - 1599
Sc1.Cons.Lg[15,2] <- Sc1.Sp.Lg[15,2] - 1036
Sc1.pCons.Lg[15,2] <- step(Sc1.Cons.Lg[15,2])
Sc1.ERLg[15,1] <- 1 - (Sc1.Sp.Lg[15,1]/Lg.2012)
Sc1.ERLg[15,2] <- 1 - (Sc1.Sp.Lg[15,2] /Lg.2012)

#Scenario 1: Rec et FSC 135 and 613 small
Sc1.Sp.Sm[1,1] <- Sm.2012 - Loss.Rec.Sm.2012 - 135
Sc1.Cons.Sm[1,1] <- Sc1.Sp.Sm[1,1] - 582
```

```
Sc1.pCons.Sm[1,1] <- step(Sc1.Cons.Sm[1,1])
Sc1.Sp.Sm[1,2] <- Sm.2012 - 135
Sc1.Cons.Sm[1,2] <- Sc1.Sp.Sm[1,2] - 582
Sc1.pCons.Sm[1,2] <- step(Sc1.Cons.Sm[1,2])
Sc1.ERSm[1,1] <- 1 - (Sc1.Sp.Sm[1,1] /Sm.2012)
Sc1.ERSm[1,2] <- 1 - (Sc1.Sp.Sm[1,2]/Sm.2012)

Sc1.Sp.Sm[2,1] <- Sm.2012 - Loss.Rec.Sm.2012 - 613
Sc1.Cons.Sm[2,1] <- Sc1.Sp.Sm[2,1] - 582
Sc1.pCons.Sm[2,1] <- step(Sc1.Cons.Sm[2,1])
Sc1.Sp.Sm[2,2] <- Sm.2012 - 613
Sc1.Cons.Sm[2,2] <- Sc1.Sp.Sm[2,2] - 582
Sc1.pCons.Sm[2,2] <- step(Sc1.Cons.Sm[2,2])
Sc1.ERSm[2,1] <- 1 -(Sc1.Sp.Sm[2,1] /Sm.2012)
Sc1.ERSm[2,2] <- 1 - (Sc1.Sp.Sm[2,2]/Sm.2012)

#Scenario 2: C&R Rec in October et FSC 1000 large
Sc2.Sp.Lg[1,1] <- Lg.2012 - CRmort.Lg.Oct.2012 - 1000
Sc2.Cons.Lg[1,1] <- Sc2.Sp.Lg[1,1] - 1036
Sc2.pCons.Lg[1,1] <- step(Sc2.Cons.Lg[1,1])
Sc2.Sp.Lg[1,2] <- Lg.2012 - 1000
Sc2.Cons.Lg[1,2] <- Sc2.Sp.Lg[1,2] - 1036
Sc2.pCons.Lg[1,2] <- step(Sc2.Cons.Lg[1,2])
Sc2.ERLg[1,1] <- 1 - (Sc2.Sp.Lg[1,1] /Lg.2012)
Sc2.ERLg[1,2] <- 1 - (Sc2.Sp.Lg[1,2]/Lg.2012)

#Scenario 2: C&R Rec in October and FSC small = 600
Sc2.Sp.Sm[1,1] <- Sm.2012 - CRmort.Sm.Oct.2012 - 600
Sc2.Cons.Sm[1,1] <- Sc2.Sp.Sm[1,1] - 582
Sc2.pCons.Sm[1,1] <- step(Sc2.Cons.Sm[1,1])
Sc2.Sp.Sm[1,2] <- Sm.2012 - 600
Sc2.Cons.Sm[1,2] <- Sc2.Sp.Sm[1,2] - 582
Sc2.pCons.Sm[1,2] <- step(Sc2.Cons.Sm[1,2])
Sc2.ERSm[1,1] <- 1 - (Sc2.Sp.Sm[1,1] /Sm.2012)
Sc2.ERSm[1,2] <- 1 - (Sc2.Sp.Sm[1,2]/Sm.2012)

#Scenario 3: no Rec et FSC (1599 large et 613 small)
Sc3.Sp.Lg <- Lg.2012 - 1599
Sc3.Cons.Lg <- Sc3.Sp.Lg - 1036
Sc3.pCons.Lg <- step(Sc3.Cons.Lg)
Sc3.ERLg <- 1 - (Sc3.Sp.Lg /Lg.2012)
Sc3.Sp.Sm <- Sm.2012 - 613
Sc3.Cons.Sm <- Sc3.Sp.Sm - 582
Sc3.pCons.Sm <- step(Sc3.Cons.Sm)
Sc3.Loss.2012 <- 613
Sc3.ERSm <- Sc3.Loss.2012/Sm.2012
Sc3.pER.Sm <- Sc3.ERSm - 0.2759
Sc3.pER.30.Sm <- step(Sc3.pER.Sm)

#Scenario 4: Rec et FSC (0 to 600 by 50 small)
for (i in 1: 13){
Sc4.Loss.2012[i,1] <- Loss.Rec.Sm.2012 + (0 + (i-1)*50)
Sc4.ERSm[i,1] <- Sc4.Loss.2012[i,1]/Sm.2012
Sc4.pER.Sm[i,1] <- Sc4.ERSm[i,1] - 0.275
Sc4.pER.30.Sm[i,1] <- step(Sc4.pER.Sm[i,1])
Sc4.Loss.2012[i,2] <- 0 + (i-1)*50
Sc4.ERSm[i,2] <- Sc4.Loss.2012[i,2]/Sm.2012
```

```
Sc4.pER.Sm[i,2] <- Sc4.ERSm[i,2] - 0.275
Sc4.pER.30.Sm[i,2] <- step(Sc4.pER.Sm[i,2])
Sc4.Sp.Sm[i,1] <- Sm.2012 - Sc4.Loss.2012[i,1]
Sc4.Cons.Sm[i,1] <- Sc4.Sp.Sm[i,1] - 582
Sc4.pCons.Sm[i,1] <- step(Sc4.Cons.Sm[i,1])
Sc4.Sp.Sm[i,2] <- Sm.2012 - Sc4.Loss.2012[i,2]
Sc4.Cons.Sm[i,2] <- Sc4.Sp.Sm[i,2] - 582
Sc4.pCons.Sm[i,2] <- step(Sc4.Cons.Sm[i,2])
}
#for 613
Sc4.Loss.2012[14,1] <- Loss.Rec.Sm.2012 + 613
Sc4.ERSm[14,1] <- Sc4.Loss.2012[14,1]/Sm.2012
Sc4.pER.Sm[14,1] <- Sc4.ERSm[14,1] - 0.275
Sc4.pER.30.Sm[14,1] <- step(Sc4.pER.Sm[14,1])
Sc4.Loss.2012[14,2] <- 613
Sc4.ERSm[14,2] <- Sc4.Loss.2012[14,2]/Sm.2012
Sc4.pER.Sm[14,2] <- Sc4.ERSm[14,2] - 0.275
Sc4.pER.30.Sm[14,2] <- step(Sc4.pER.Sm[14,2])
Sc4.Sp.Sm[14,1] <- Sm.2012 - Sc4.Loss.2012[14,1]
Sc4.Cons.Sm[14,1] <- Sc4.Sp.Sm[14,1] - 582
Sc4.pCons.Sm[14,1] <- step(Sc4.Cons.Sm[14,1])
Sc4.Sp.Sm[14,2] <- Sm.2012 - Sc4.Loss.2012[14,2]
Sc4.Cons.Sm[14,2] <- Sc4.Sp.Sm[14,2] - 582
Sc4.pCons.Sm[14,2] <- step(Sc4.Cons.Sm[14,2])

#Scenario 5: Rec Oct et FSC (0 to 600 by 50 small)
for (i in 1: 13){
Sc5.Loss.2012[i,1] <- CRmort.Sm.Oct.2012 + (0 + (i-1)*50)
Sc5.ERSm[i,1] <- Sc5.Loss.2012[i,1]/Sm.2012
Sc5.pER.Sm[i,1] <- Sc5.ERSm[i,1] - 0.275
Sc5.pER.30.Sm[i,1] <- step(Sc5.pER.Sm[i,1])
Sc5.Loss.2012[i,2] <- 0 + (i-1)*50
Sc5.ERSm[i,2] <- Sc5.Loss.2012[i,2]/Sm.2012
Sc5.pER.Sm[i,2] <- Sc5.ERSm[i,2] - 0.275
Sc5.pER.30.Sm[i,2] <- step(Sc5.pER.Sm[i,2])
Sc5.Sp.Sm[i,1] <- Sm.2012 - Sc5.Loss.2012[i,1]
Sc5.Cons.Sm[i,1] <- Sc5.Sp.Sm[i,1] - 582
Sc5.pCons.Sm[i,1] <- step(Sc5.Cons.Sm[i,1])
Sc5.Sp.Sm[i,2] <- Sm.2012 - Sc5.Loss.2012[i,2]
Sc5.Cons.Sm[i,2] <- Sc5.Sp.Sm[i,2] - 582
Sc5.pCons.Sm[i,2] <- step(Sc5.Cons.Sm[i,2])
}
#for 613
Sc5.Loss.2012[14,1] <- CRmort.Sm.Oct.2012 + 613
Sc5.ERSm[14,1] <- Sc5.Loss.2012[14,1]/Sm.2012
Sc5.pER.Sm[14,1] <- Sc5.ERSm[14,1] - 0.275
Sc5.pER.30.Sm[14,1] <- step(Sc5.pER.Sm[14,1])
Sc5.Loss.2012[14,2] <- 613
Sc5.ERSm[14,2] <- Sc5.Loss.2012[14,2]/Sm.2012
Sc5.pER.Sm[14,2] <- Sc5.ERSm[14,2] - 0.275
Sc5.pER.30.Sm[14,2] <- step(Sc5.pER.Sm[14,2])
Sc5.Sp.Sm[14,1] <- Sm.2012 - Sc5.Loss.2012[14,1]
Sc5.Cons.Sm[14,1] <- Sc5.Sp.Sm[14,1] - 582
Sc5.pCons.Sm[14,1] <- step(Sc5.Cons.Sm[14,1])
Sc5.Sp.Sm[14,2] <- Sm.2012 - Sc5.Loss.2012[14,2]
Sc5.Cons.Sm[14,2] <- Sc5.Sp.Sm[14,2] - 582
Sc5.pCons.Sm[14,2] <- step(Sc5.Cons.Sm[14,2])}
```